Tampere University

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ASSESSMENT FOR USING BLUETOOTH COMMUNICATION TECHNOLOGY UNDER INDUSTRIAL CONDITIONS. TESTBED IN MOBILE MACHINE ENVIROMENT.

Master´s thesis
Faculty of Engineering and Natural Sciences
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ABSTRACT

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Master´s Thesis
Tampere University
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The purpose of this master´s thesis is to investigate the possibilities of using wireless communication using the IEEE802.15.1 radio protocol, in mobile machines with a CAN bus that Kalmar Oy supplies to its customers. The work focuses on the mobile machines, which works with electric power. Mobile machines are used to move products in ports. This thesis focuses on how to make communication work between the mobile machines, and what kind of advantages this technology brings between these mobile machines operating in ports.

Information about the technologies used in the research was collected from literature and internal documentation. Theoretical information about the use of the CAN bus in mobile machines is available from several sources and studies. Wireless data transfer technologies have also been researched a lot. The theoretical part focuses on the information obtained from information communication technology standards, teaching materials and literature studies. Empirical data for the final work was collected by participating in the work of the R&D programming department of Kalmar's mobile machines and by building a demo version of Bluetooth communication between the mobile machines.

In this study, the connection of wireless communication technology to the programmable logic controller will be reviewed, and the configurations of the components used in the testing equipment will be presented, as well as the functions performed with the software to make the communication between the mobile machines. At the end of the work, the results of the wireless data transfer between mobile machines will be reviewed.

Keywords: Bluetooth, communications protocol, WLAN, programmable logic

TIIVISTELMÄ

Jyri Lepistö: Arviointi Bluetooth-viestintätekniikan käytöstä teollisissa olosuhteissa. Testattu liikkuvien työkoneiden ympäristössä.
Diplomityö
Tampereen yliopisto
Automaatiotekniikka
Lokakuu 2022

Tämän lopputyön tarkoituksena on tutkia radioprotokollalla IEEE802.15.1 toimivan langattoman viestinnän käyttömahdollisuuksia CAN-väylän omaavissa liikkuvissa työkoneissa, joita Kalmar Oy toimittaa asiakkailleen. Työ keskittyy tuotteita siirtelevään liikkuvaan työkoneeseen, joka toimii sähkövoimalla. Liikkuvia työkoneita käytetään tuotteiden siirtämiseen satamissa. Tämä lopputyö keskittyy siihen, miten kommunikointi saadaan toimimaan liikkuvan työkoneiden välillä sekä minkälaisia etuja tämä teknologia tuo näiden satamissa toimivien sähköllä toimivien liikkuvien työkoneiden välillä.

Tiedot tutkimuksessa käytettävistä teknologioista kerättiin kirjallisuudesta sekä sisäisistä dokumentoinneista. Teoreettista tietoa CAN-väylän käytöstä liikkuvissa työkoneissa on useista lähteistä ja tutkimuksista saatavilla. Myös langattoman tiedonsiirron teknologioita on tutkittu paljon. Teoriaosuudessa keskitytään tietoliikennetekniikan standardeista, opetusmateriaaleista sekä kirjallisuustutkimuksista saatuihin tietoihin. Lopputyön empiirinen tieto kerättiin osallistumalla Kalmarin liikkuvien työkoneiden R&D-ohjelmointiosaston työntekoon sekä rakentamalla demoversio Bluetooth-kommunikoinnista liikkuvien työkoneiden välille.

Tässä tutkimuksessa käydään läpi langattoman viestintäteknologian yhdistämistä ohjelmoitavaan logiikkaohjaimeen sekä esitellään testauslaitteistossa käytettävien komponenttien konfigurointeja sekä esittelemällä minkälaisia toimintoja ohjelmistoilla tehdään, jotta saadaan kommunikointi liikkuvien työkoneiden välillä toimimaan. Työn lopussa käydään läpi tuloksia langattomasta tiedonsiirrosta liikkuvien työkoneiden välillä.

Avainsanat: Bluetooth, kommunikaatio protokolla, WLAN, ohjelmoitava logiikka

PREFACE

When I started to study for higher education, the person who supported my education from beginning told me: “For the courses it is enough that you get those accepted, but your thesis must be good and focus on technology you’re interested”. Thank you for believing me to achieve this and pushing me to learn more Petri.

I would like to thank you Ville Saari from Kalmar and Mikko Helminen from Coresbond to accepting my proposal for topic of the final thesis. I also would like to thank you Jussi Halmela and Mika Leppalahti for technical support and sharing information about used technologies.

I also would like to give great gratitude to my wife, for supporting me achieving my goal to learn something new.

Tampere, 16 October 2022

Jyri Lepistö

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LIST OF SYMBOLS AND ABBREVIATIONS

ANSI	American National Standards Institute
ASC	Automatic Stacking Crane
CAN	Controlled Area Network
CHE	Container Handling Equipment
CPU	Central Processing Unit
DC	Direct Current
DM	Data Memory
EM	Extended Data Memory
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IoT	Internet of Things
ISM	Industrial, Scientific, and Medical
ISO	International Organization for Standardization
ITU	International Telecommunication Union
I/O	Input/Output
JTC1	Joint Technical Committee
LAN	Local Area Network
LD	Ladder Diagram
LMP	Link Manager Protocol
M2M	Machine to Machine
OSI-model	Open System Interconnection model
PLC	Programmable Logic Controller
RF section	Radio Frequency section
RFID	Radio-Frequency Identification
RMG	Rail Mounted Gantry crane
SC	Straddle Carriers
ST	Structure Text
SFC	Sequential Function Chart
SHC	Shuttle Carriers
SIG	Special Interest Group
STS	Ship-To-Shore
TT	Terminal Tractors
USB	Universal Serial Bus
WLAN	Wireless Local Area Network
WPAN	Wireless Personal Area Network

λ	lambda, wavelength
c	light speed
f	frequency
Hz	Hertz
Ω	Ohm, resistance

1. INTRODUCTION

This thesis is study of wireless communication and control system of container handling equipment used in Kalmar shuttle manufacturing. In example in harbour infrastructure there are cranes, shuttles, buildings, and fences. People are connected to infrastructure, peoples are walking in container yard, are using shuttles and other different machines, so safety in very important thing to think with in these machines. Today there is more possibilities for wireless communication for industrial solutions. Electronics have been cheaper and smaller, so it has been possible to make devices which communicates with radio signals. Target for this thesis is to study and solve is the Bluetooth communication correct technology between mobile machines. Bluetooth communication is meant to replace Wireless Local Area Network (WLAN) communication that has been used.

The first chapter concentrates to an introduction for purpose, goal of thesis and introduction about Kalmar. First chapter also gives preface of methods how the research is made. The theoretical part of researched technologies is literature study of communication technology and used hardware in communication and control system.

Chapter 2 gives theoretical introduction about communication technologies and communication and control system that were used in thesis. Different parts of the control system have been developed, and communication between machines have been developed a lot. There is different kind of wireless communication protocols that are possible to use, and to convert fixed bus protocols into wireless protocols.

The third chapter introduces the case study that was installed and tested in Kalmar´s shuttle. First there is introduction how the communication was tested in the laboratory conditions, and then how it was made between mobile machines.

1.1 Kalmar Oy

Kalmar offers solutions for handling cargo at ports, terminals, and distribution facilities. Kalmar is a pioneer in the field of automated terminals and achieving energy efficiency in container handling. Kalmar product portfolio includes straddle and shuttle carriers, reach stackers, empty container handlers, terminal tractors, and forklift trucks. Kalmar offers also offers support services like maintenance contract, technical support, spare parts, training, and crane upgrades and Kalmar One automation system.

At the end of 2021, Kalmar had more than 4800 employees in 30 countries, of which the largest were United States, Malaysia, Sweden, China, Finland, Poland, Spain and the Netherlands.

At the end of 2021, Kalmar had orders received in value of 2063 million euros. Kalmar is part of Cargotec, which sales in 2021 were totaled approximately 3.3 billion euros and it employs approximately 11500 people. [1]

1.2 Purpose and goal

For modern industry, automation is important support, and main target if automation is to make efficiency increase and certify operation. With advanced automation systems and different new communication technologies there is lot of new possibilities with wireless connectivity. Wireless connectivity has multiple advantages like quick and easy installation, better flexibility, and good communication ranges. As mobile solutions become more common, possibilities for communication between mobile solutions come more needed. There is difference between wireless network protocols and some applications may need quick connections between machines, so pairing is needed to do quickly in certain time.

Used network protocol in mobile solutions is Controlled Area Network (CAN). There is a need to have wireless communication between mobile solutions that is easily connected and ended. Main goal of this work is to investigate how CAN-Bluetooth gateway works between two Programmable Logic Controllers (PLC) that controls shuttle and carriers.

1.3 Research methods

Start of the research was mainly theoretical. At first there was reading of technical topics related to communication networks, industrial internet of things and literature review of communication protocols.

The operation of wireless communication presented in this thesis is based on written publications and empirical material. Empirical information and skills have been gathered in courses organized at the University of Tampere and by practically building a demo version of Bluetooth communication between logics in the premises of Kalmar.

1.4 Research scope

There are originally mobile machines communicating with sensors and actuators via CAN-bus to PLC, and PLC communicates in Wireless Local Area Network (WLAN) with other machines or systems PLC. Machines PLC communicates also in Local Area Network (LAN) with automation control room, where operator uses automation controls.

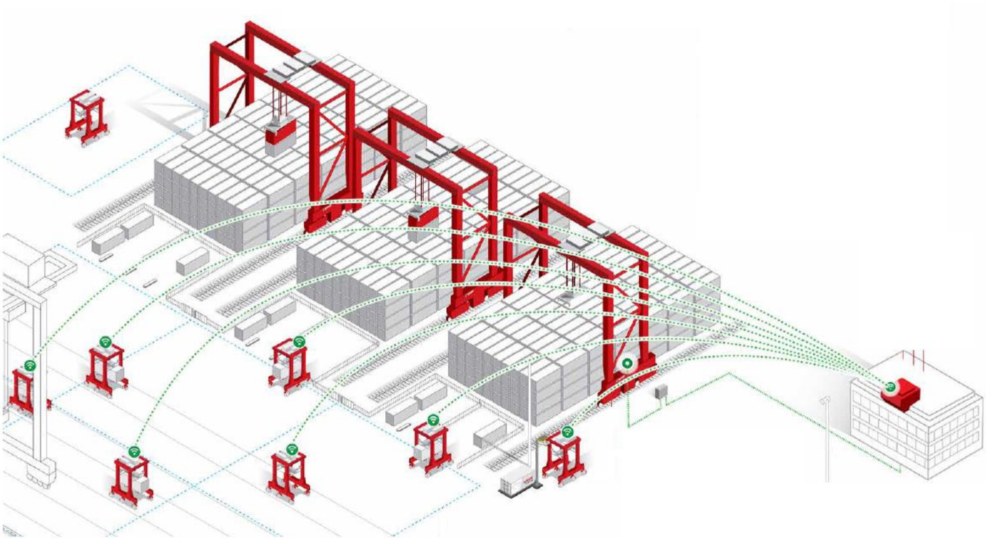

Figure 1. *Original network*

First was needed test between one master Bluetooth node and one slave Bluetooth node. After that it is needed to add other Bluetooth slave nodes, so would other slaves interrupt communication between originally connected master and slave.

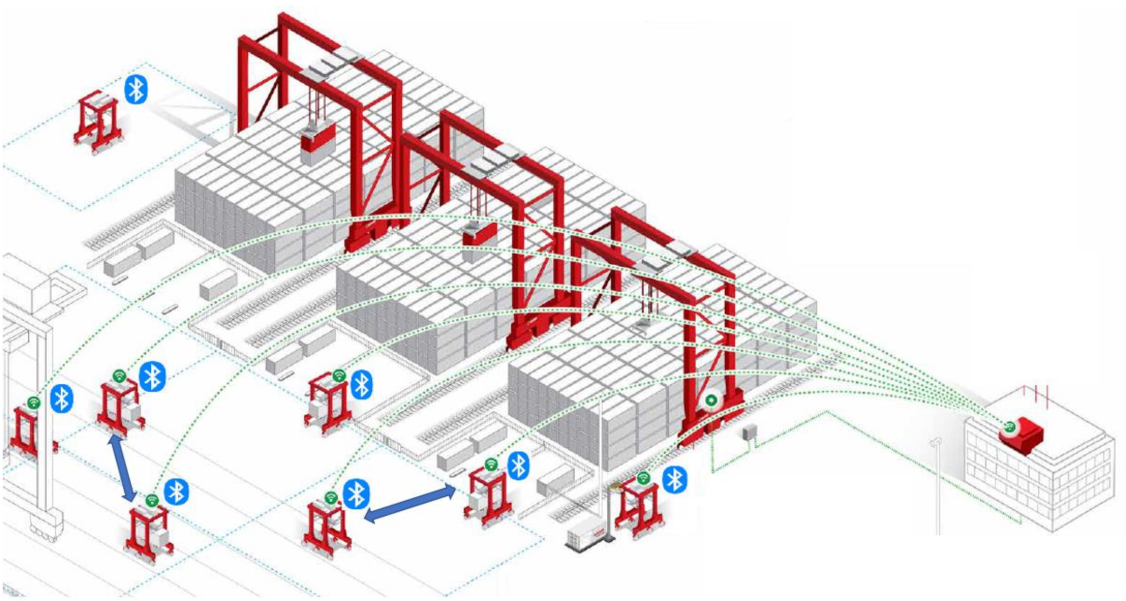

Figure 2. *New network with Bluetooth*

Stable machine PLC´s Bluetooth node is marked as master, and Mobile Machine PLC Bluetooth nodes are marked as slaves.

2. THEORETICAL BACKGROUND

In this chapter gives information about technologies that has been researched so there is possible to understand more detailed of the technologies behind the subject of the thesis.

There is important to be familiar with communication technologies and different protocols that are used in mobile machines. Automation has developed and communication technologies also. It is also important to understand network topologies in machines before there is possible to understand fully how the software is needed to build. When the basics of the communication networks is understood it is easier to get familiar with what is needed to take consideration when two machines have communication link between each other.

2.1 Communication technology

Existing communication systems (LAN, WLAN, mobile networks, etc.) are meant to do data transmission and the speed and delays in networks are in such way that high-definition video streaming and video calls are possible in good quality. There is lot of data transfer capacity, so services can be provided to large number of users.

Telecommunications is not disappearing nowhere in the future, it will become more important when it is needed to efficiently transmit information between people, machines, or between people and machines.

2.1.1 Standardization

Communication systems works in large area and there is lot of component and software suppliers. Prerequisite for compatibility of different products and components is that suppliers use commonly agreed technical policies in standard organizations. Most important standard organizations in communication sector are:

- International Telecommunication Union (ITU) there is lot of standards from modeling the propagation of radio waves to compression methods. ITU is also responsible at the international level for satellites orbits and the allocation of radio frequencies for different uses.
- ISO/IEC Joint Technical Committee 1 (ISO/IEC JTC1) sets standards in the field of information technology and develops standards related to e.g. cybersecurity,

Internet of Thing (IoT), smart cards (debit cards, SIM cards, etc.) and to voice and video compression methods (MPEG).

- American National Standards Institute (ANSI) is American standard organization cooperative institution which participates in ISO operations. ANSI as member Institute of Electrical and Electronics Engineers (IEEE) is world´s largest association of technical professionals, which has created e.g., IEEE 802-series LAN standards.

2.1.2 Networks

Wired network topology describes how networked devices are configured physically, that normally are computer, printer or other network hardware like a hub, switch, or router. Between two devices the simplest link is point-to-point wired link. With this point-to-point connection there is two topologies for wired networks, bus, and ring.

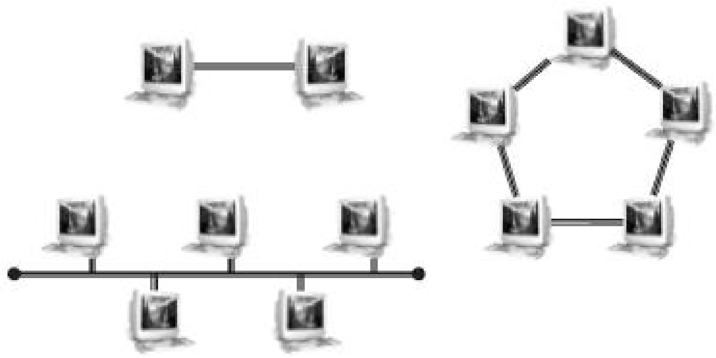

Figure 3. *Simplest link between devices*

Example with passive hub, there is possibility to control data flow from devices in network. Repeater in the central point for LAN cabling in star and tree topologies.

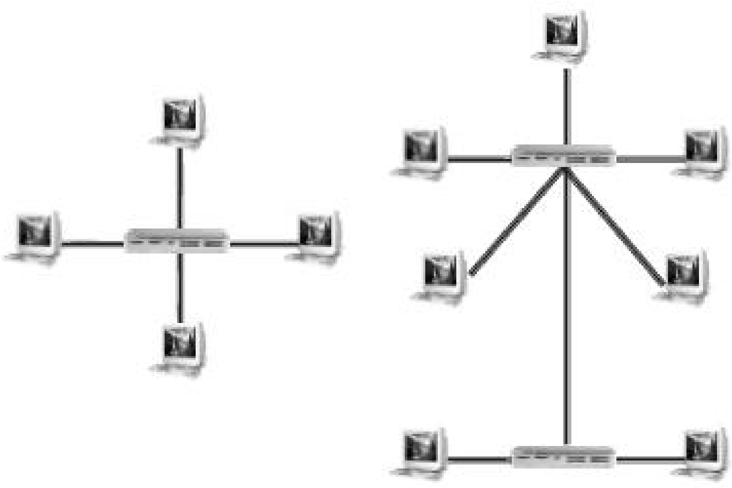

Figure 4. *Star and Tree topologies*

2.1.3 Protocols

According to TechGenix 2020 [2] open system interconnection reference model (OSI-model) creation was started in the late 1970s and there were targeted to find common standard for the architecture of networking systems. In the OSI-model there is seven levels of communication for computer protocol architecture [3] and in the levels has functions to perform in each level.

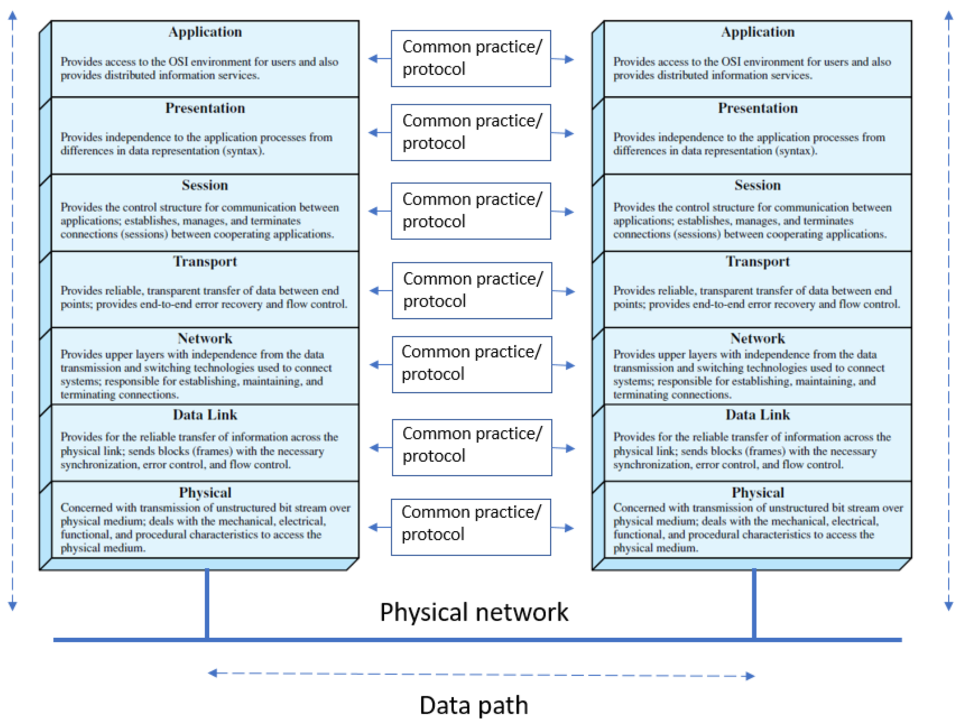

Figure 5. *OSI levels*

There is possibility to translate how different protocols to each other.

2.2 Wireless communication

Different kind of wireless communication has come very popular, and technology has been evolved very much. In wireless communication signals are transferred uncontrolled over the media without a physical wiring. Depend on the transmission media, signal can be electronic, electromagnetic (radio, infrared, optical) or acoustical [4].

2.2.1 Propagation of radio waves

The propagation of radio waves depends on the carrier frequency of the signal. Propagation of the radio wave is possible in Ground wave propagation, Sky-Way propagation and Line-of-Sight propagation, like is seen in figure 6 [4].

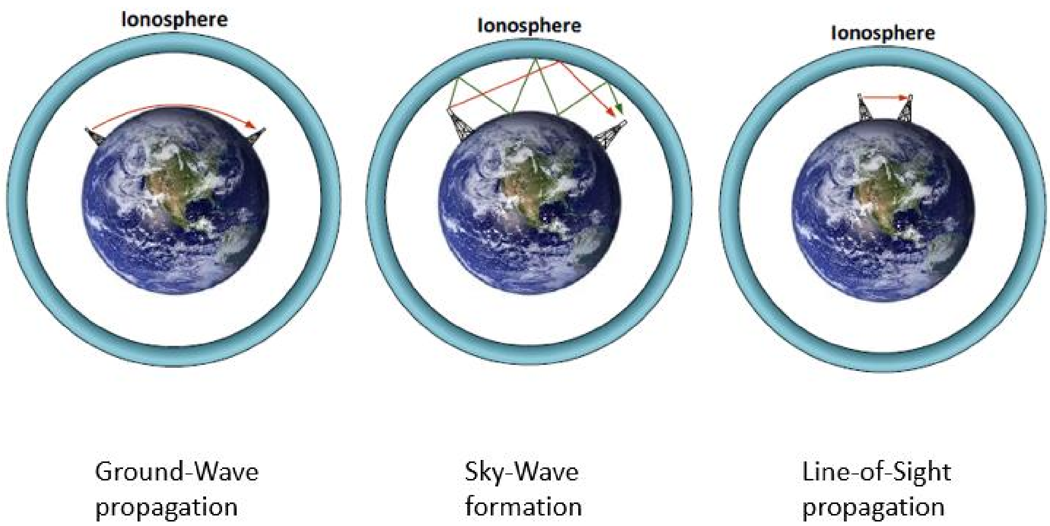

Figure 6. *Propagation of radio waves*

There in connection between the frequency and wavelength. Wavelength is inversely proportional to the frequency that calculated by formula 1 [4].

$$\lambda = c/f \quad (1)$$

were

λ = wavelength

c = speed of light

f = frequency

The frequencies of visible lights are proximity 430-750THz and radio waves are 30 Hz to 3 GHz.

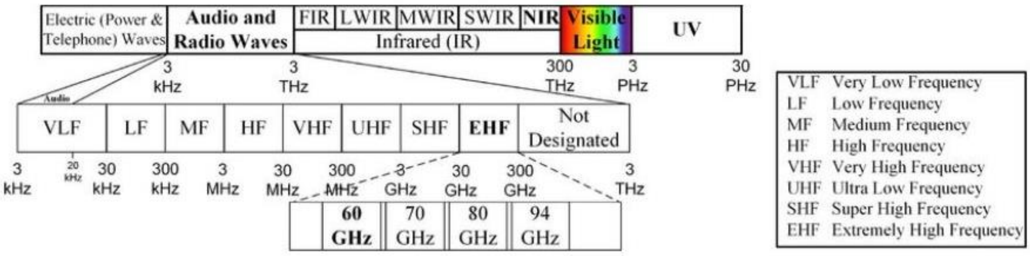

Figure 7. *Radio frequency spectrum*

Different frequencies have different wavelengths, so it has different lengths where it can move signal. Low frequencies have wider wavelength than higher frequencies.

2.2.2 Wireless digital Communication overview

The basic part of communications system is the communication channel. Wireless communication uses radio waves propagating in free space as the communication channel. Almost all communication systems input signal is needed to convert into a suitable form for transmission over the communication channel and then back into the needed form for the end-user. These parts are called transmitter and receiver.

Parts in the transmitter are encoder, modulator, radio frequency section (RF section) and antenna. There is possible that input is an analog or digital signal. Analog signal is converted into digital format using sampling and quantization. The encoder converts data into form that is more resistant to degradation of communication channel losses, like shadow effect, shadowing is the effect the received signal power fluctuated due to objects obstructing the propagation path between transmitter and receiver. The modulator modulates signal to required carrier frequency and modifies signal characteristics. [5]

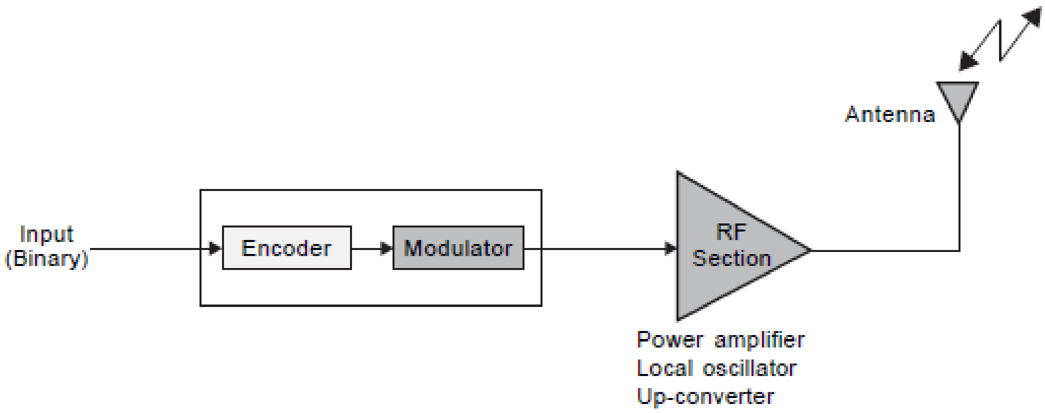

Figure 8. *Transmitter structure*

2.2.3 Antennas

Key component for wireless link is the antenna, which couples' electromagnetic energy between the transmitter to receiver [6]. For radio communication the selecting correct antenna is important. Antenna is transducer for converting guided signals in a transmission line or waveguide into electromagnetic radiation in an unbounded medium or vice versa. Antenna material, shape, and size impact the radiation and impedance. Usually used antennas are dipole antennas and directional antennas [7].

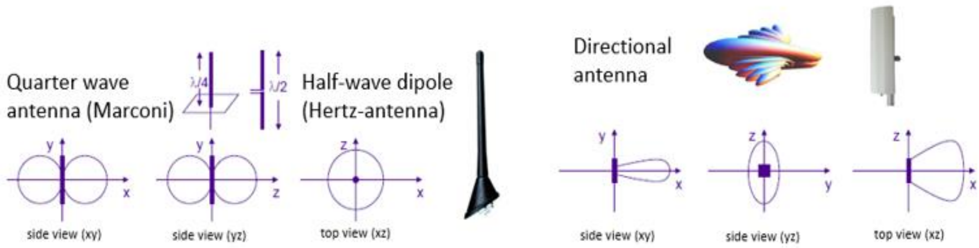

Figure 9. *Antenna examples*

2.3 Bluetooth technology

Bluetooth is technology well established and it is used in wide range of devices that uses short-range radio link like example between speakers to tv or mobile phones, PS4 controllers or other mobile and portable devices. Bluetooth technology is developed significantly and has been expanded to provide connectivity for IoT and Machine To Machine (M2M) communications. Bluetooth Special Interest Group (Bluetooth SIG) [8].

Bluetooth technology uses same frequencies as Wi-Fi and use of technology is designed for short distances. Bluetooth technology devices has use cases for different areas example in:

- Phone accessories for smartphone wireless communication
- Smart building automation sensors
- Health equipment

Bluetooth have different evolved generations with new features, and Bluetooth is compatible with all previous versions. Example the Bluetooth 4 were designed in 2014 for Internet of Things (IoT) and Bluetooth 5 came with extended battery life and increased outdoor transmission range from 50 to 200 meters.

2.3.1 Bluetooth history

The Bluetooth technology started off as an idea to develop wireless short-range connection between items like a cordless headset with devices like mobile phone, from mobile phone supplier company Ericsson in 1994.

The Bluetooth Special Interest Group (SIG) was founded in 1998 by five corporations: Ericsson, Nokia, IBM, Toshiba, and Intel, that is an industry group that develops Bluetooth technology for demands that has been growing for wireless innovations. Bluetooth refers to IEEE 802.15.1 code. Today standard is managed by the Bluetooth SIG. Bluetooth SIG develops the Bluetooth standards and has provided it faster speed and more flexible [9].

2.3.2 Bluetooth General Description

Bluetooth is wireless technology for short-range communications system that is intended to replace cables. The Bluetooth core system consists of and RF transceiver, baseband, and protocol stack.

The RF handles transmitting and receiving information packets on the physical channel. In physical layer The Bluetooth RF operates in 2.4 GHz ISM (Industrial, Scientific, and Medical) band. Layering of links, channel, and partner control protocols are placed over the physical channel.

Each Bluetooth device contains a one of a kind Bluetooth address characterized to it that be utilized for recognizing distinctive devices from each other. Bluetooth device can support asynchronous data channel, up to three simultaneous data channel or a channel which at the same time bolster asynchronous data and asynchronous voice. To include unwavering quality, Bluetooth employments recurrence bouncing scheme, where the recurrence bouncing bases on the clock of piconet´s master device.

2.3.3 Bluetooth protocol architecture

The basic protocols that Bluetooth devices have implemented are baseband, Link Manager Protocol (LMP), Logical Link Control and Adaption Protocol (L2CAP), Link Controller (LC).

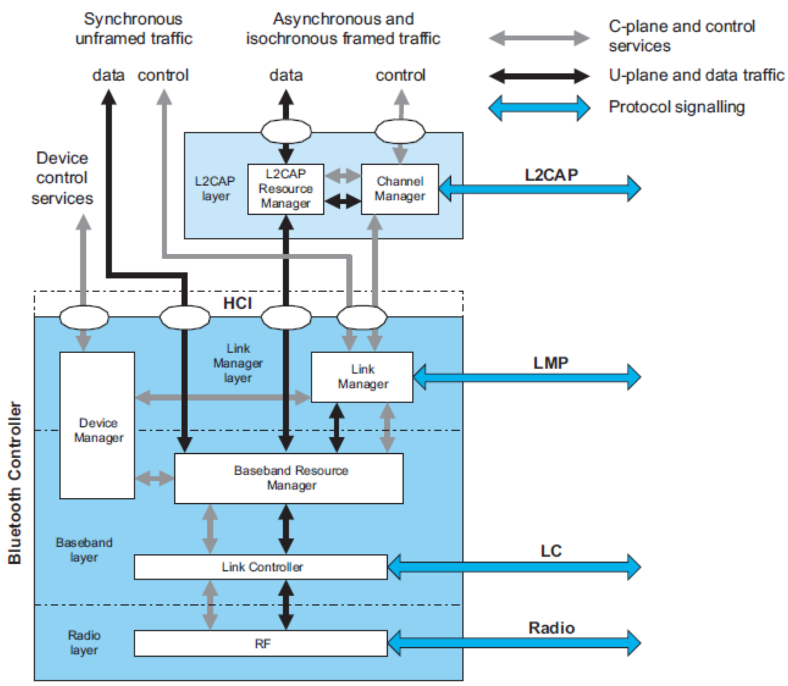

Figure 10. *Core Architecture*

L2CAP “handles” the link control for packets that contain upper layer payload while LPM under HCI takes care of other link controlling. L2CAP provides protocol multiplexing, segmentation and reassembling for upper layers connection oriented or connectionless data services.

The Bluetooth link controller manages Bluetooth packet encoding and decoding from data payload and parameters relevant to the physical channel, logical transport and logical connection.

The link manager is responsible of the creation of logical link and updating of parameters related to physical links between devices. Link manager achieves this by communicating with the link manager in remoter Bluetooth devices using the LMP. [10]

2.3.4 Bluetooth topology and network architecture

For wireless personal area networks (WPAN) in IEEE 802.15.1-2005 is mentioned possibility to use two different topologies, the point-to-point, or the point-to-multipoint topology, this depends on the application requirements.

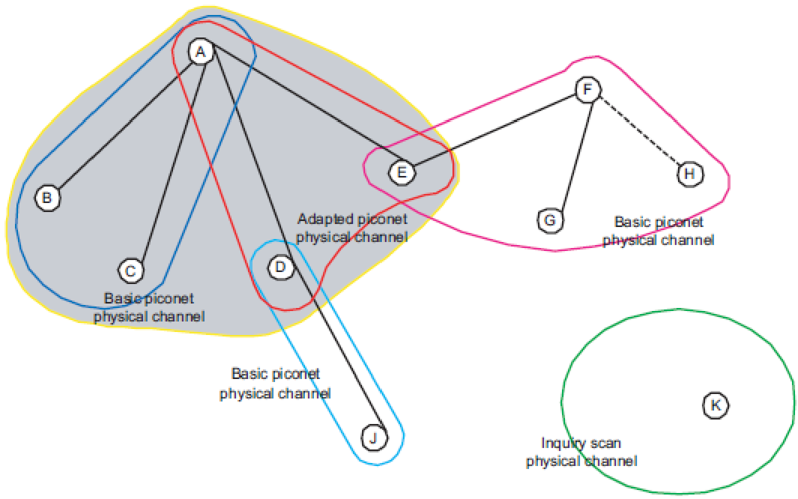

Figure 11. *WPAN topology examples*

Basic Bluetooth network architecture is piconet. Piconet is ad-hock network where the synchronization of frequency hopping is the same across all devices. In each Piconet one device hold the role of master node and rest devices are slaves. Device can be a slave in several independent Piconets but cannot be a master of more than one Piconet [12]. Limit of connected slaves in a Piconet, is seven devices. If there are more than seven slaves, they need be at “parked” state. There can be 255 “parked” slaves per piconet with direct addressing defined by the Bluetooth SIG [13].

A Bluetooth device that is member of two or more Piconets is said to be involved in a Scatternet. The Bluetooth core protocol don’t offer functionality to Bluetooth device to imply any network routing capability. This is outside the scope of the Bluetooth Core Specification and is the responsibility of higher-level protocols.

In Figure 11 is an example of Bluetooth topology. Device A is a master in a piconet with slave’s devices B, C, D and E this is piconet A. There are two other piconets are in example: piconet F where device F is master and devices E, G and H are slaves. Piconet D where device D is master and device J is slave.

2.3.5 Bluetooth security architecture

The Bluetooth security model has five different separate security features: pairing, bonding, device authentication, encryption, and message integrity.

- Pairing: the process for creating one or more shared secret keys
- Bonding: the act of storing the keys created during pairing for use in subsequent connections to form a trusted device pair
- Device authentication: verification that the two devices have the same keys

- Encryption: message confidentiality
- Message integrity: protects against message forgeries

Security architecture has evolved with the development of Bluetooth technology and has several security mechanisms [10].

Main purpose of Bluetooth security mechanism is to provide an appropriate level of protection for use of Bluetooth in global environment. For the users that are requiring more solid protection are encouraged to use stronger security mechanisms available in network protocols and application programs. [11]

All Bluetooth devices have 48-bit long device address that is unique, devices also have 128-bit random number for authentication. For encryption for handshake there is private encryption key, what changes from 8 to 128 bits. For last comes regularly changing 128-bit long pseudo number that device creates itself.

2.4 Controlled Area Network

CAN is a fieldbus for connecting actuators and devices inside of a system or subsystem. CAN communication protocol was developed by R. Bosch GmbH in beginning of 1980s and first CAN chip was offered to car manufacturers in late 1980s by Intel. Since 1994-1995, CAN is the most common protocol in automotive applications, and is described in the ISO standards [14].

Automation solutions use the CAN protocol to send and receive small amounts of data with real-time requirements. The CAN protocol is defined as and international standard by 150 International Standard Organizations. [15]

2.4.1 CAN-protocol

CAN is used transfer protocol to send data and receive data in networked devices and actuators within a system or sub-system. The speed is up to 1Mb/s. The data transfer rate depends on length if the bus. Message frames are used to send and receive data. Standard CAN, version 2.0A and Extended CAN 2.0B are the two message frame formats that the CAN protocol supports.

In version 2.0A there is identifier that is 11 bits long, allowing 2048 different logical addresses, so 2048 different messages are possible sent in a network if no additional distinctions are performed. In version 2.0B there is identifier that is 29 bits long and this allows 2^29 different messages and it is called Extended Frames.

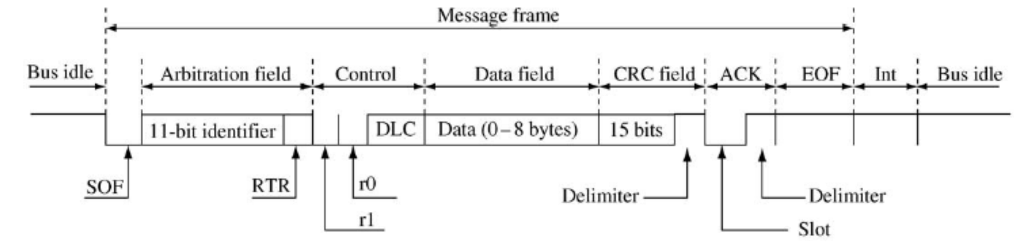

Figure 12. *CAN 2.0A message frame*

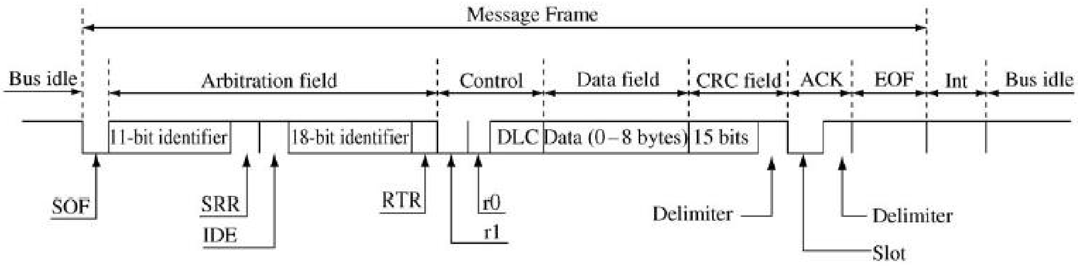

Figure 13. *CAN 2.0B message frame*

In CAN Protocol there is four types of frames included: Data Frame, Error Frame, Remote Frame and Overload Frame. Transported data in send only in Data Frame. Others are for fault containment, triggering and synchronization situations.

2.4.2 CAN-bus

In ISO 11898 standard specification has used twisted-pair cable and have achieved up to 1Mbit/s signaling rate with bus length of 40m and maximum of 30 nodes. CAN network topology need to have 120 Ω resistors in the start and end of cabling. This is bus terminate at both end matching characteristic impedance of the line to prevent signal reflections that are presented in figure 6. as RT [16].

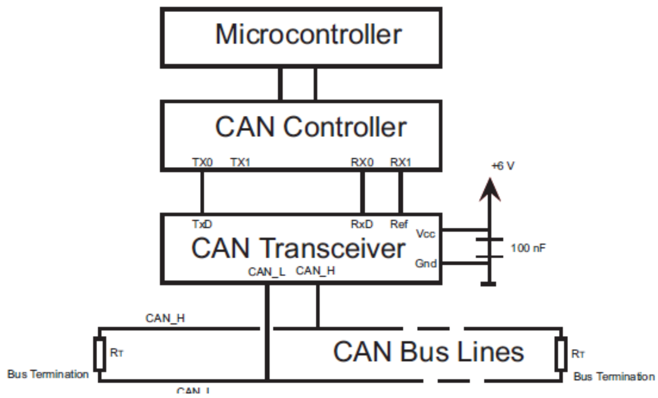

Figure 14. *CAN bus architecture*

Cable in CAN-bus might be an unshielded or shielded twisted-pair cable. There is normally D9-connector used in connections and there is possible to have termination resistor in the connector.

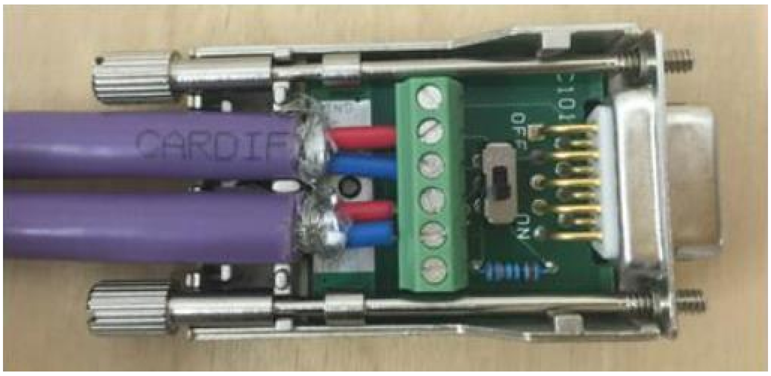

Figure 15. *CAN-connector*

For vehicles with multiple electrical systems running over CAN-bus, shielded cable is advisable. For applications with few connections or short wire runs, unshielded cable may be adequate.

2.5 Communication Components

Used components in communication, are PLC, User Defined CAN Unit and CAN-Bluetooth bridge. User Defined CAN Unit is installed in same rack with PLC unit and CAN-Bluetooth bridge is installed in the CAN-bus.

2.5.1 Omron CJ2 PLC

The SYSMAC CJ2-series Central Processing Unit (CPU) units are multifunctional CPU units with fast performance and large memory capacity. Units have Built-In Ethernet/IP port with universal Ethernet communications like data links between PLC´s.

Figure 16. *CJ2H-CPUxx-EIP Unit*

CJ2 CPU units have readable programming environment with features like addressing Data Memory (DM) and Extended Data Memory (EM) area bits, that makes programming easier. Ladder diagram (LD), Structure Text (ST) and Sequential Function Chart (SFC) programming can be combined in the user program. [17]

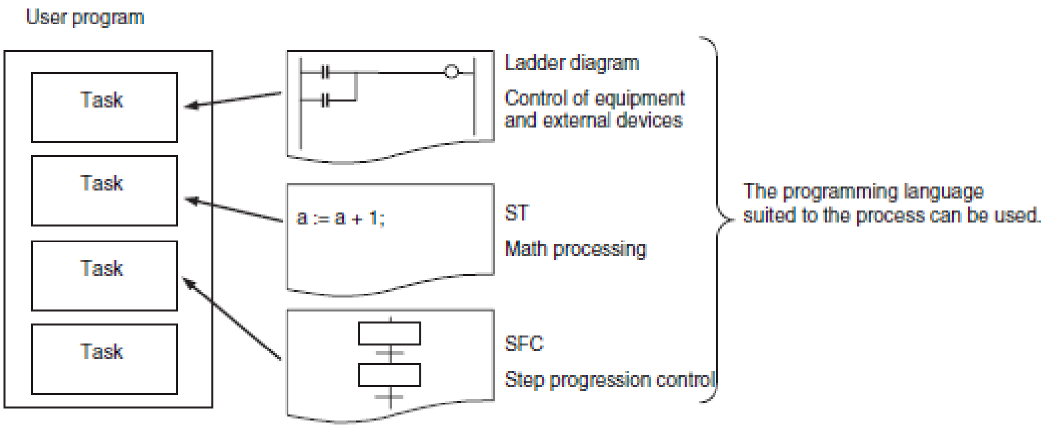

Figure 17. *Programming Languages*

CPU writes data to the internal I/O memory areas, while it cyclically executes user´s programs. Data is exchanged externally when I/O is refreshed, and peripherals are serviced.

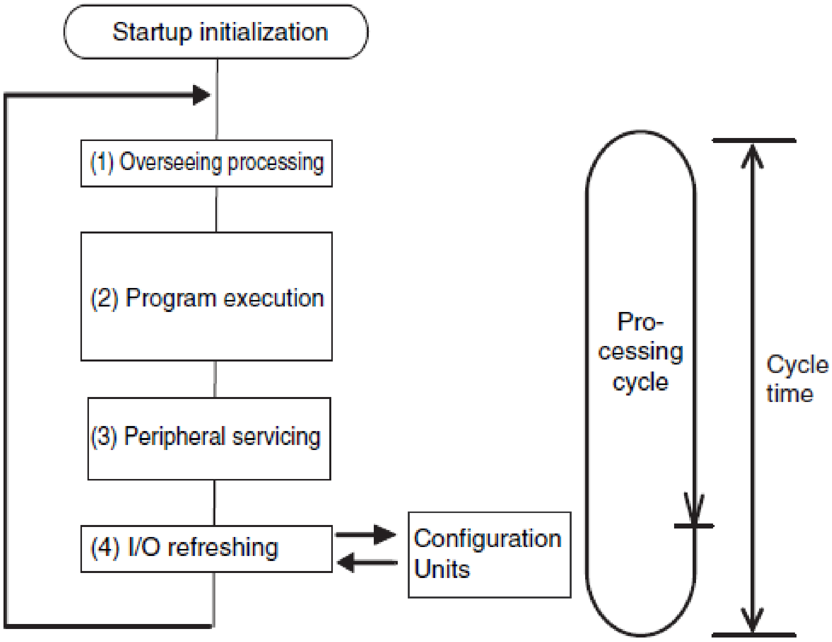

Figure 18. *CPU Unit Internal Operation*

At startup initialization certain processes are performed when power is turned on to the PLC. [17]

- Detecting connected Units (I/O allocation)
- Comparing the registered I/O tables and the connected Units
- Clearing the non-holding areas in I/O memory according to the status of the IOM Hold Bit
- Clearing forces status according to the status of the Forced Status Hold Bit
- Autobooting using the autotransfer files In the Memory Card if one Is inserted
- Performing self-diagnostic (user memory check)
- Restoring the user program
- Updating the PLC Setup

2.5.2 Omron CJ Ethernet/IP

Omron CJ series of PLC´s can be equipped with and Ethernet/IP scanner. With this PLC can initiate connections to other Ethernet/IP devices. There are build-in Ethernet interfaces for CJ2M and CJ2H PLC types.

The units organize the data they exchange between the supported communication network and the PLC in Tag sets and Tags. A Tag is a reference to memory location in the CJ PLC. The reference can be by memory address or name [17].

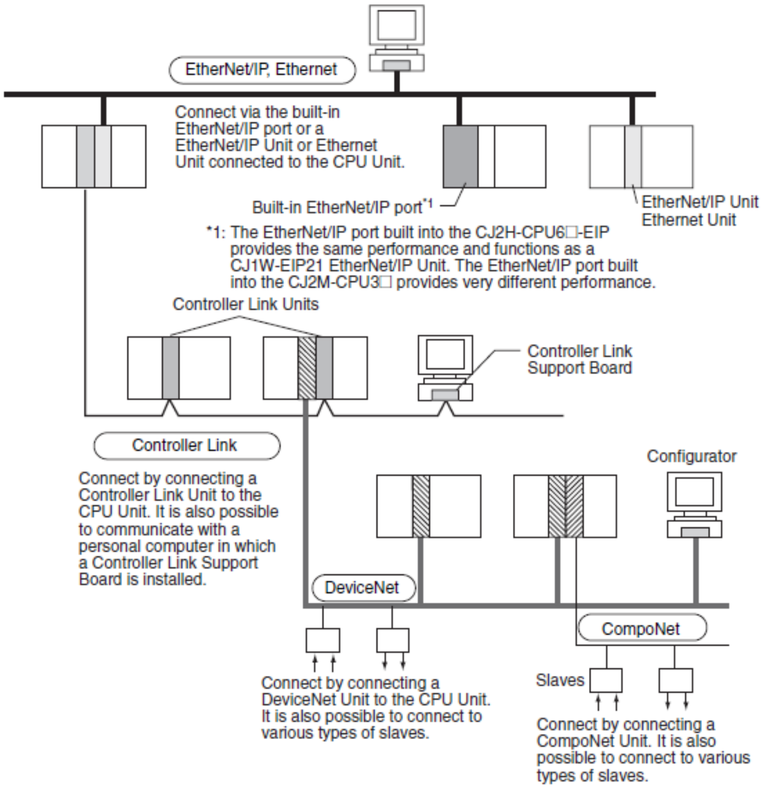

Figure 19. *Communication networks example*

2.5.3 Omron User Defined CAN Unit

The User Defined CAN Unit (CJ1W-CORT21) is a CPU Bus Unit, that is possible to install into controller. Unit will interface between the CPU and CAN bus.

There is possible to mount 16 CPU Bus Units on the CPU Rack or an Expansion Rack. The User Defined CAN Unit supports message communications exchange with the CPU [19]. Four types of services are supported:

- Configurations: configure specific memory locations, number of input and output messages, set the identifiers and method of sending the output message, set the identifiers of the input messages, and set the bit rate of the CAN physical layer
- Transmission: services to send specific output message
- Error log: services to read and clear the error log
- Identification Services: Services to identify the Unit and its firmware version

2.5.4 IEC-61131 Standard

IEC 61131 is an international standard based on programmable logic developed by the International Electrotechnical Commission. A continuum of programmable logics increases in use, increasing complexity of systems and lack of a standard were the reasons why that standard was developed. The purpose of the standard Is to create a consistent vision for industrial automation about what languages should be used and how. For comply the standard manufactures must demonstrate which components meet or do not meet the requirements, for programming systems this implies that these may be expected to implement a subset of the standard´s details, but not all of them. [20]

The IEC 61131 standard consists of two main parts, which are the general elements and the programming language. General elements include data types, variables, configurations, resources and tasks, while the programming language consists of graphics and text-based programming languages.

2.5.5 PROEMION CAN-Bluetooth bridge

With PROEMION CAN-CAN Bluetooth bridge, CAN data is possible to transmit wirelessly between two CAN bus systems via Bluetooth connection. After switching on, connection is automatically established between configured master and slave device. Data is exchanged bidirectionally as soon as the connection between two devices has been established.

Figure 20. *CANlink Bluetooth bridge*

2.5.6 PROEMION SOFTWARE

Proemion CANlink wireless Configurator is used to device configuration. With configurator there is possible to make configuration and download configurations to CANlink wireless modules. Also, it is possible to upload configurations from CANlink wireless modules to computer.

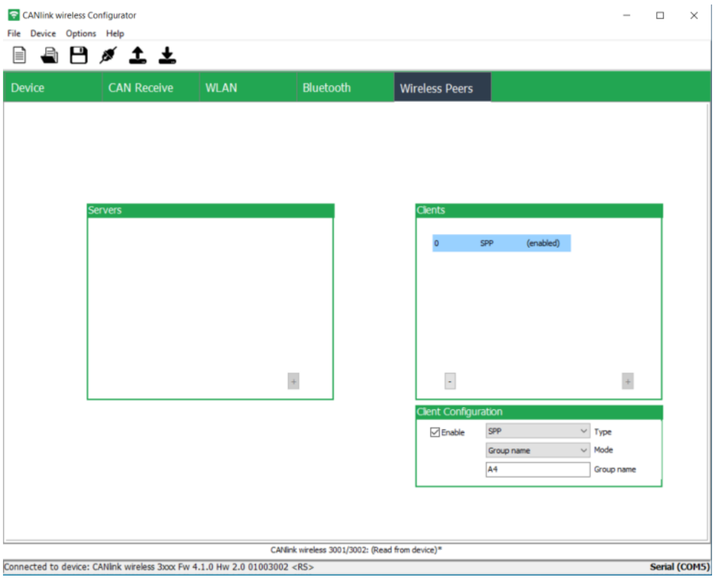

Figure 21. *CANlink wireless configurator*

The program starts without loaded configuration and without a connection to the CANlink wireless module. [21]

2.6 Terminal area

In harbor terminal area there is different groups of machines for container handling equipment (CHE). In CHE includes Ship-To-Shore cranes (STS), Shuttle Carriers (SHC), Straddle Carriers (SC), Terminal Tractors (TT), Rail Mounted Gantry crane (RMG), RTG crane and Automatic Stacking Cranes (ASC).

SHC, SC and TT handles containers in ground, carries the containers to defined place where system has it marked.

2.7 Shuttles

Third Generation Shuttle Carriers can pick and place containers directly on the ground and transport containers from quayside to landside into container terminal or yard and allows cranes to operate all the time at their optimal schedule.

There are different models in port shuttle carriers, that has different kind of power sources, advanced safety features, and there is possible to have manual or automated control system. [23]

2.7.1 Hybrid Shuttle Carrier

Hybrid Shuttle Carrier has diesel-electric drive and regenerative energy system that captures electrical braking and spreader-lowering energy and stores this for re-use in Lithium-ion batteries.

Figure 22. *Hybrid Shuttle Carrier*

2.7.2 FastCharge Shuttle Carrier

FastCharge Shuttle Carrier uses electric drive units with the latest battery technology, that can be charged on the during shuttle carriers work cycle.

Figure 23. *FastCharge Shuttle Carrier*

2.8 FastCharger

The FastCharge solution uses the local power grid to supply electricity to charge the onboard batteries of the Shuttle machines. An actively controlled DC (direct current) output is created by first converting the supplied electricity to the necessary voltage level, filtering it, and the converting it to the charging contact.

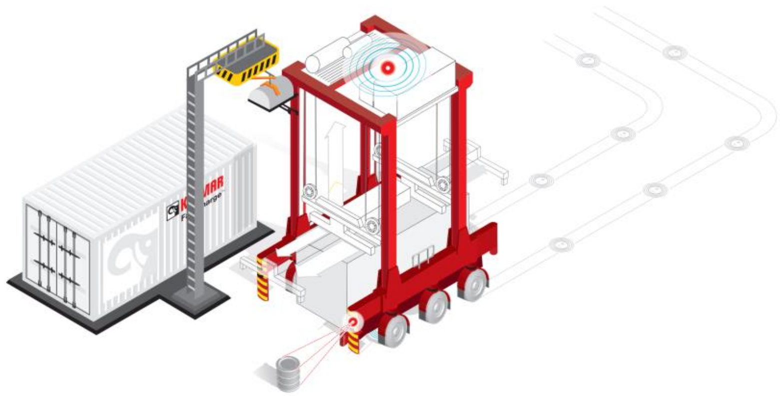

Figure 24. *Shuttle in charger area*

For connecting to the local power grid supply, there is possible to change from low voltage (<1kV) to medium/high voltage levels (>1kV). [22]

3. METHODOLOGY AND MATERIALS

This chapter presents additional material for researched technologies in chapter 2. The purpose of this research is a test system for Bluetooth communication between mobile machines. This section is presented from Kalmar perspective, because used hardware and software is used in Kalmar products.

Communication between mobile machines is important part of the process where mobile machines are working in same area. Bluetooth communication is in the development phase, so research is helping in configuration the connection.

3.1 Research phases

There were different phases in the research. There was a lot of readings and getting familiar with hardware and software used in testing. It was needed to make testing equipment for communication test between Bluetooth bridges.

Research started with studying programmable logics (PLC) and Kalmar Shuttle PLC program and CAN-fieldbus communication. In second phase there was needed to get familiar with Proemion CAN-Bluetooth bridge modules, and Proemion Software. New software and new protocol were hard to start being used, because these has not been used before. There were readings from manuals and standard specifications.

When used hardware's and software's was getting more familiar and protocols was understanded there was able to understand how the programs was needed to work and how the configuration was needed to send from PLC to CAN-Bluetooth bridge data was changed between two PLC throw CAN-Bluetooth bridge.

In the final state there were implementation for testing with test equipment and documentation. When testing was made in test equipment there came time to complete final documentation.

3.2 PLC system hardware

Programmable logics are electronics devices equipped with one or more microprocessors that control process devices through the inputs and outputs or buses based on programs and parameters stored into memory.

Programmable logic system is built either from modular units or of compact integrated input and output units, memory and from the power source. It is also possible to connect to small compact units to expansion units. In larger systems, multiple logics and other devices are connected to each other through different channels, so that data exchange between logics and other connected devices is possible. [24]

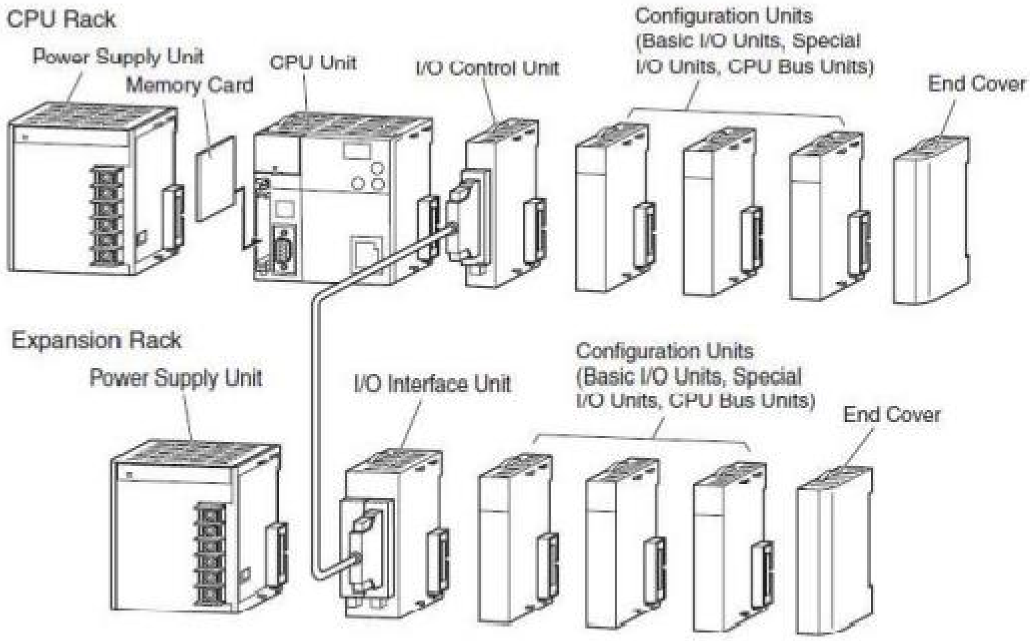

Figure 25. *Example of modular logic system*

For modular type of PLC systems capacity is allowed to be scaled and modular systems offer simpler troubleshooting.

3.3 PLC system software

A PLC is and industrial computer adapted to control various processes such as assembly lines, machines, or other activities requiring high reliability, easy programming, and process error diagnostic. Mobile machine and other system PLC has been built by using Omron CX-Programmer software where is conceivable to utilize IEC 61131-3 standard in programming. IEC 61131-3 includes ladder diagram, function block diagram, structure text content, instruction list and sequential work chart programming languages.

There can be certain workflow with PLC system construction with CX-Programmer from design to online debugging on the actual machines, on-site operation and adjustment.

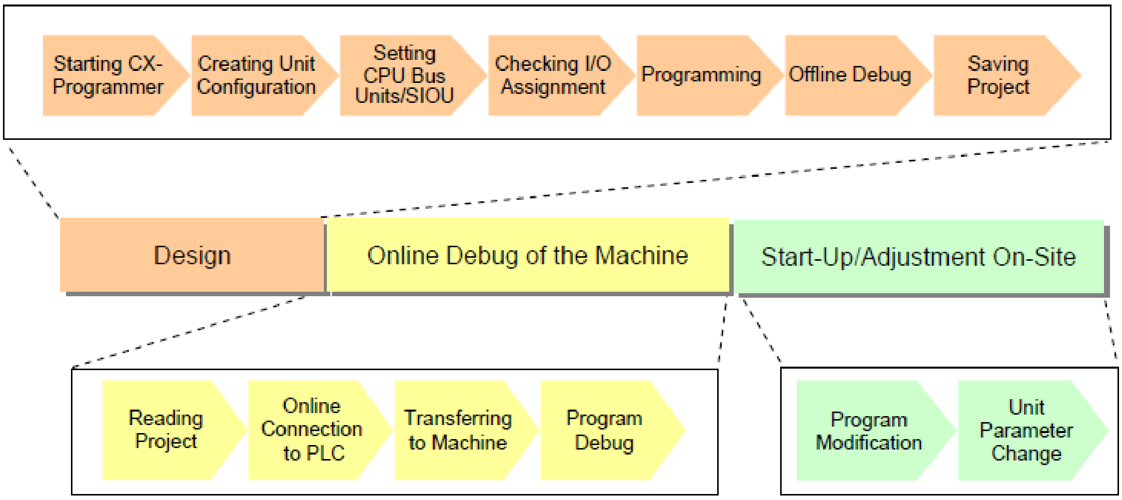

Figure 26. *Design, online debugging and star-up workflow*

3.3.1 Omron CX-Programmer

For Omron PLC programming to start, the CX-Programmer is started. With CX-Programmer programs for Omron PLC is created. When creating new project, selection for PLC model comes at first.

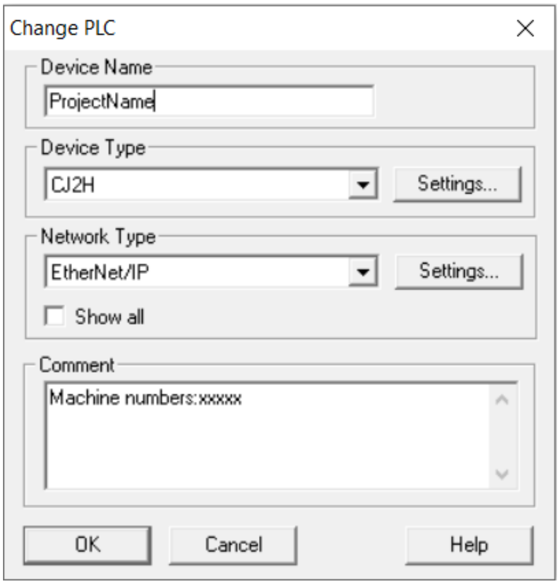

Figure 27. *PLC model selection*

When selected PLC device type then from settings comes different CPU type possibilities for certain PLC device type. For using Function Blocks there are certain PLC device models, CJ2H, CS1G-H, CS1H-H, CJ1G-H, CJ1H-H and CJ1M.

Devices and modules that are installed to CPU Rack, are parametrized in IO Table and Unit Setup selection.

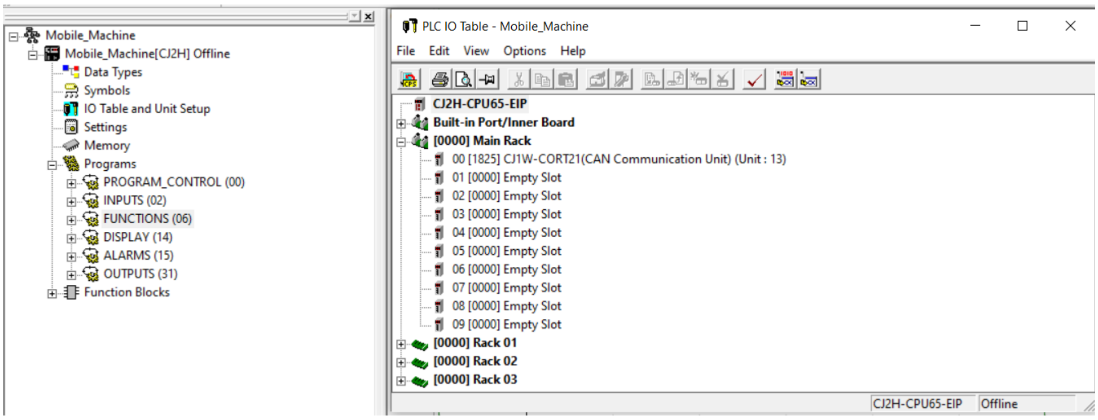

Figure 28. *Unit configurations*

Connected digital input and output units that are connected to the main rack are defined in IO Table and Unit Setup.

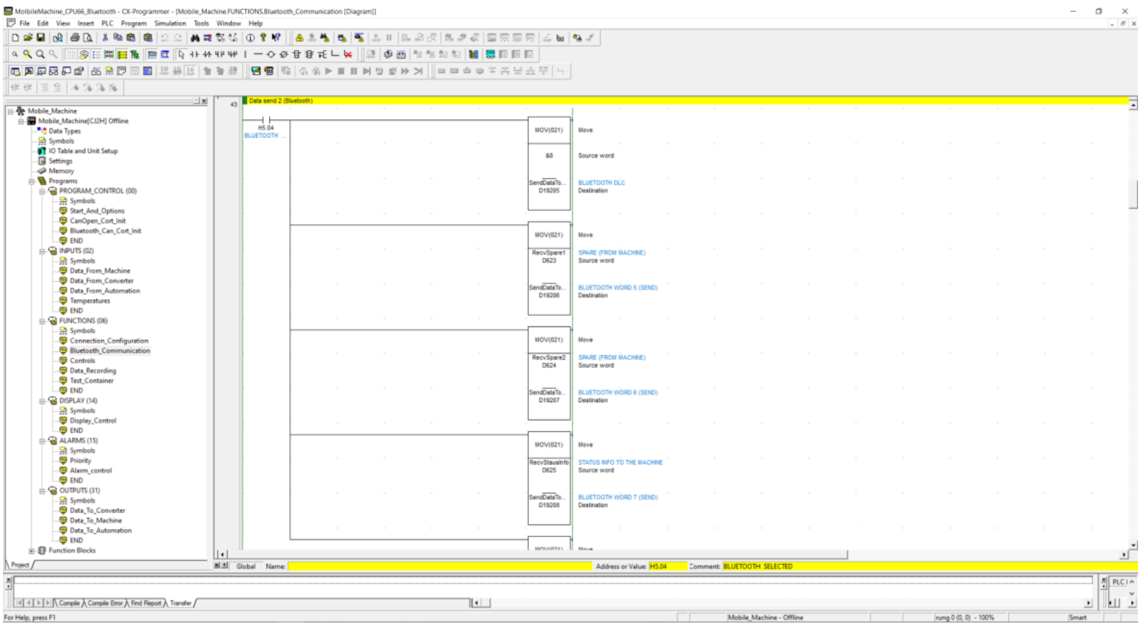

Figure 29. *CX-Programmer main window*

Executable program is created in the part at project tree, where sections of executable programs consist of. In the right side of programmed functions for PLC to execute.

3.3.2 PLC programming

The most basic PLC programming include control instructions like switching, logic, counting and timing. Various programming languages have been developed [24]. A textual programming language for mathematical operations and calculations. Graphical programming languages are used more due to their simplicity and easier understanding of program flow and purpose.

Structured text is also a text-based programming language that resembles traditional in its appearance programming (e.g., C-language).

```
(*DATA CONVERT*)
Value_real := INT_TO_REAL (Value);
Samples_real := INT_TO_REAL (Samples);

(*CALCULATION*)
Help1 := Value_real / Samples_real;
Help2 := Value_real + 0,01;
Help3 := Value_real - 0,01;

Average := Average / Samples_real * (Samples_real - 1,0) + Help1;

IF Value_real < Average AND Average < Help2 THEN
    Average := Value_real;
END_IF;

IF Value_real > Average AND Average > Help3 THEN
    Average := Value_real;
END_IF;

Average_uint := REAL_TO_INT (Average) ;

```

Figure 30. *Structured test example*

Ladder diagram is graphical programming language that consist of left and right vertical lines and coils and contacts between them. Contacts mean, for example, inputs, and a coil departure.

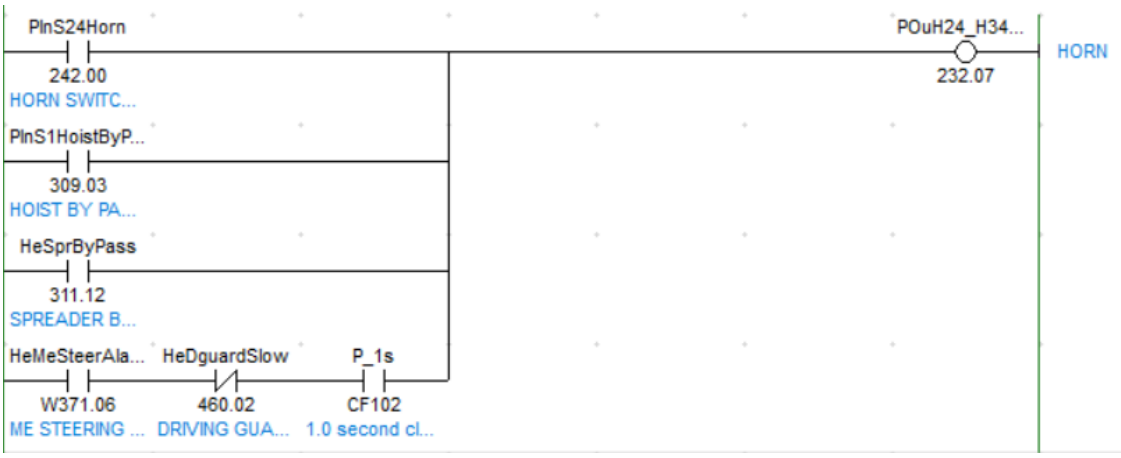

Figure 31. *Ladder diagram example*

Function block diagram is also a graphical programming language where the “code” consists of boxes and from the lines drawn in between. The code is executed from left to right and it is possible to divide it into its own code blocks, called networks, with horizontal lines.

Figure 32. *Function block diagram example*

Sequential function chart is also graphical programming language that enables chronological order between different functions. Transitions between steps may be programmed in Ladder or Structured Text languages.

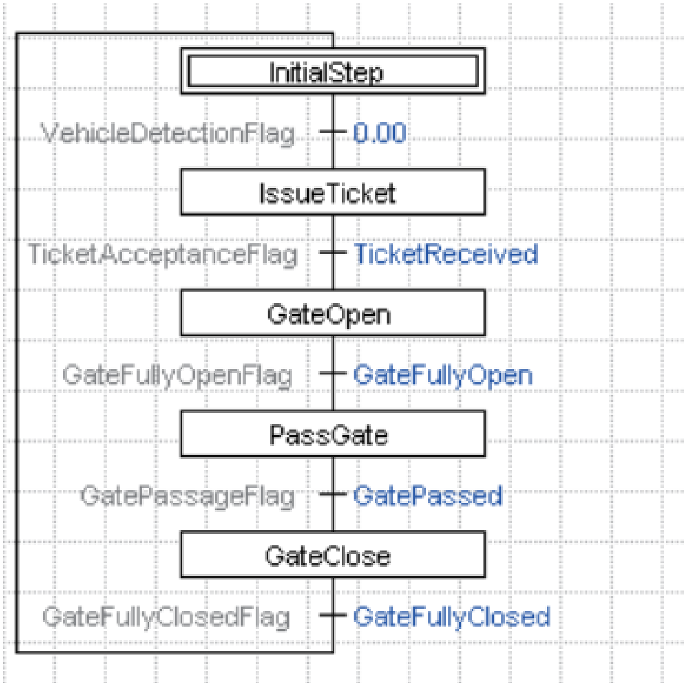

Figure 33. *Sequential function chart example*

3.3.3 Mobile Machine PLC test software program configuration

Mobile Machine PLC main task is to control mobile machine work movements and communication between other Mobile Machines.

For Mobile Machine there are different parts in program that controls machines parts. There is subroutine for inputs, that handles different sensor and information gathered from actuators. Also, there is subroutine for outputs, that controls actuators and electrical devices that are used in Mobile Machine. These input and outputs are parts of remote

I/O that communicates in CAN network. There is different kind of subroutines for controlling engine, spreader, display and other different functions that are needed to have safety use of Mobile Machine.

3.3.4 Stable Machine PLC test software program configuration

Stable Machine PLC main task controls Stable Machine electrical functions and communication between Mobile Machine and main control room.

For Stable Machines there are also subroutines for controlling the charger process, input, and output handling, display and other different functions that are needed to have so charger process is safely handled between the Mobile Machines and Stable Machines.

3.3.5 CAN communication

Communication between Mobile Machine and Stable Machine PLC´s using CANlink Bluetooth bridge was first needed to solve what parameters was needed to change and how the parameters were able to through CAN-bus. Configuration parameters to CAN-Bluetooth bridge was send through CAN-bus, these parameters indicators were mentioned in CANlink wireless Series 3000 Communication Profile Area manual. [26]

There is automatically handled node control for different parts of in Mobile Machine and Stable Machine. With node controlling memory area for sending and receiving buffering is needed to have when information exchange between nodes is done. It is handled like guided in Omron CJ1-CORT21 User Defined CAN Unit operational manual. [19]

CJ1W-CORT21 has several states when power has putted on or reset has been done.

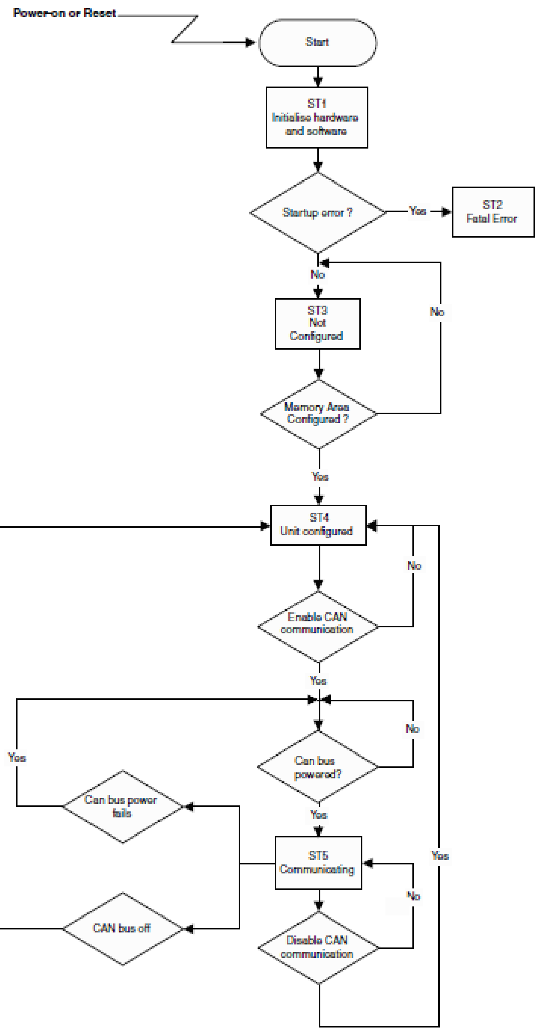

Figure 34. *CJ1W-CORT21 Unit states*

At state 1 (ST1) unit executes start-up test and initializes the CPU bus connection. For state 2 (ST2) there is start-up error detected during ST1. For state 3 (ST3) unit has started without errors in ST1 but is not yet configurated using message commands. At state 4 (ST4) Unit has received the memory locations and number of output and input message buffers. In state 5 (ST5) Can messages can be sent and received if the network is powered.

3.3.6 Proemion software

Proemion software were used in the start of work, so it could be possible to get more familiar with used CAN-Bluetooth bridge modules. With software there were needed to make basic configurations to CANlink modules, so it was able to test information exchange. With modules there is possible to use Bluetooth or WLAN communication so correctly made configurations was needed to do. There were included manuals for start to use devices and software. Basic configurations were made by the Proemion manuals, and by reeded information from protocols. To modify the configuration of CANlink 3001 modules it its firstly need to connect device to PC with USB serial port connection.

3.3.7 CANlink module 3001 and 3002

The CANlink wireless supports the transmission of pure CAN messages to another device. No direct protocol interpretation is configured in the firmware. This makes possible to use the device for different applications with various CAN transport protocols.

CANlink modules can be used as CAN-CAN-Bluetooth bridge, that enable wireless data transmission if CAN data between two CAN bus system. After switching on, a connection is automatically established between a configurated master and a slave device. Data is exchanged bidirectionally as soon the connection between two devices has been established. [24]

Devices are factory set configuration correspond with the slave configuration. So able to have two devices communicate, other must be configurated as the slave and other as the master.

4. TEST SYSTEM IMPLEMENTATION

This chapter it gets more familiar about software and hardware configurations that are used between Mobile Machine and other machines. During implementation phase test hardware was built to simulate communication between Mobile Machine and other machines. Test hardware gives real network figure when there is one Stable Machine PLC and one Mobile Machine PLC. This hardware configuration is possible to be used in every customer deployment.

There gets also explained how the CANlink module gets configurated from PLC and how the process would be needed to handle in the communicating process. This also gives possibilities for different development for using this communication in machines.

4.1 Test hardware

Two stations with Omron CJ2H PLC´s was build. The Bluetooth – CAN gateway is designed to be used for wireless communication between two PLC. The Gateway is installed on the PLC CAN bus as a part of nodes and redirects bus message to the other PLC by using Bluetooth technology.

Test equipment´s was built in din rail, for possibility to use equipment´s in the R&D department and in the test room. Test equipment includes 3 Omron CJ2H-CPU65-EIP PLC with CJ1-CORT21 cards, 2 Proemion CANlink Wireless 3000 and 2 Proemion CANlink Wireless 3001 modules. The Electrical supply of the components was obtained from the adjustable power unit. The PLC units were connected to the CAN bus with CANlink Wireless modules.

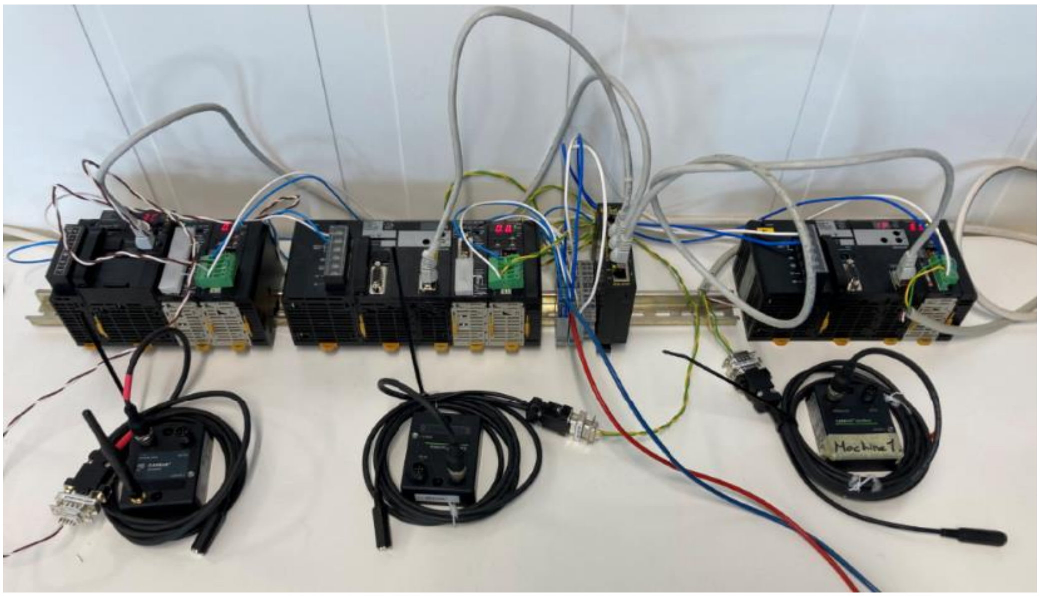

Figure 35. Used test hardware

4.1.1 CPU unit

The Omron CJ2H-CPU65-EIP has built-in flash memory and built-in RAM. Built-in RAM is used as execution memory and the built-in flash memory is used as backup memory. CPU is clocked in 62,5 MHz, and has controllers for all built-in communication interfaces, and LED indicators for showing state of CPU. It has peripheral pot, universal serial bus (USB), with USB 2.0-compliant B-type connector, serial port with EIA RS-232C interface and Ethernet/IP port for use of TCP/IP, UDP, ARP, ICMP (ping only) and BOOTB protocols.

Indicators in the front show's status of the CPU, that shows is the CPU in the MONITOR or RUN mode, when the program is being executed. Or does CPU be in ERROR / ALARM state. Indicators shows also is the CPU communicating throw USB port. Seven-Segment indicator in CPU shows the Ethernet/IP IP-address. Left side of 7-segment indicator is status indicator of built-in Ethernet/IP port that shows example module status, network status and communication status.

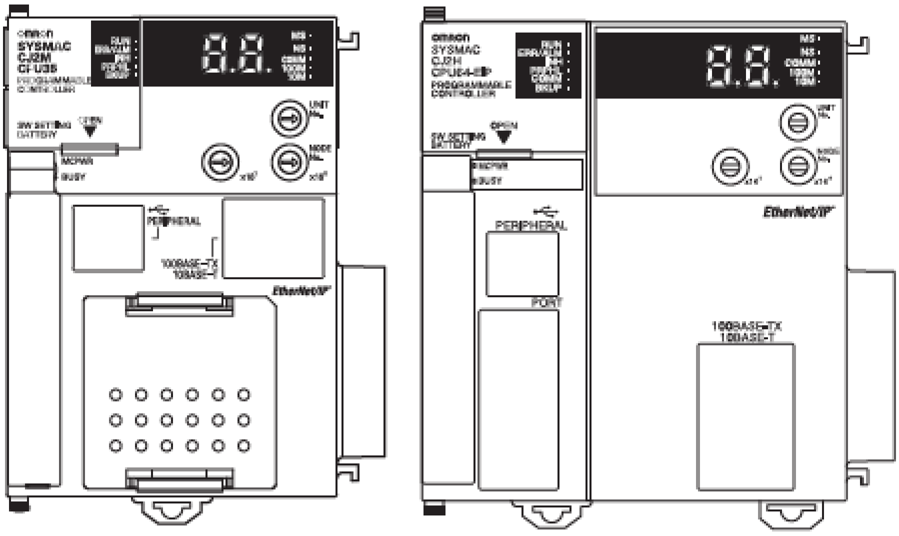

Figure 36. *Omron CJ2M and CJ2H CPU models*

4.1.2 CAN communication unit

Omron CJ1-CORT21 User Defined CAN Unit enables CAN communication with PLC. Module is mounted right side of CJ2-CPU65-EIP. Module has XW4B-05C4-T-D communication connector for bus-cable. To this connector also 11 to 25 VDC power supply voltage for unit Is also supplied.

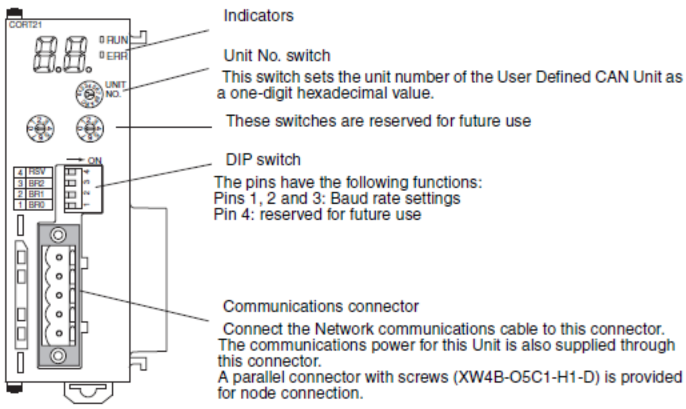

Figure 37. *Omron User Definet CAN Unit*

User Defined CAN unit is equipped with following indicators that indicate the operating status of the node itself and the overall network. Status indicators on the front are labelled as RUN and ERR. Unit has also Seven-Segment indicator that normally indicates the enabled or disabled status of communication.

Proemion CANlink wireless has 32-bit Cortex M4 microcontroller, 1024kB expansion Program Flash memory. Needed supply voltage is 8-32VDC. It has ISO 11898-2 High-Speed interface, and Bluetooth and WLAN operating modes. Used Bluetooth version is Bluetooth Classic (2.1+EDR).

4.1.3 CANlink wireless

In CANlink wireless 3001 antenna is internal, and in CANlink 3002 antenna is external. Using external RF-antenna where is RP-SMA antenna connector send and receive bluetooth signals is possible.

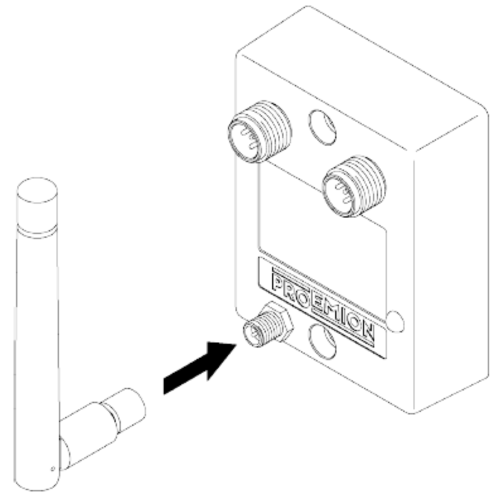

Figure 38. *Proemion CANlink 3002 module*

In the front of device there is LED that indicates functions and status of device. [19] There are different status in device example when device has activated connection and when device is in malfunction state.

4.2 Omron PLC programming

The Omron CX-Programmer software is used to design of this study´s test PLC´s. For program there is used LD and ST programming languages. Features for compiling and Show Address Reference Tool are important for programming Omron PLC.

The test program for Machines PLC program is divided for program parts that are called PROGRAM_CONTROL, INPUTS, FUNCTIONS, DISPLAY, ALARMS, and OUTPUTS. Portions of these programs includes detailed sections for used functions for machine process.

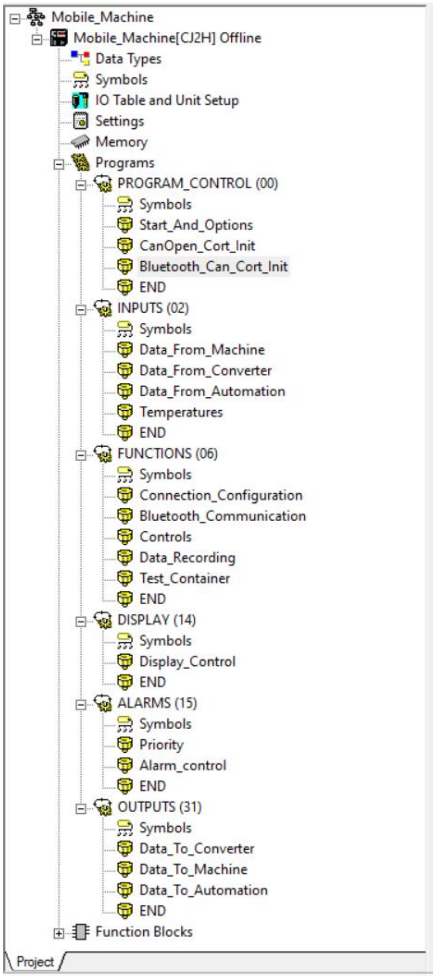

Figure 39. *PLC programs*

For testing Bluetooth communication main program parts used are PROGRAM_CONTROL includes sections for start and stop options, and setting used memory areas for CAN communication used with CANlink wireless modules.

FUNCTIONS have section for Bluetooth communication where is identified data what are changed between Mobile Machine and other machines.

4.3 Communication configuration

At CAN communication build in Omron PLC starts with unit configuration. Each unit in the network is needed to configurate in the software configuration. Process of the network and unit configuration contains

- Building the physical network topology
- Defining the bus parameters, baud rate and bus timing parameter sample point

- Defining the configuration data, i.e., defining the process data that is exchanged between the User Defined CAN Unit and the other nodes in the CAN network
- Defining the parameterization data for the User Defined CAN Unit, including the filtering of the message identifiers and the configuration of the message buffers in the CPU system.

Parameterization of the User Defined CAN Unit, memory areas and message parameterization must configurate in every power-up. The software configuration steps must do every time when unit has started, the correct way to operating with this process is:

1) Setting memory area (buffer) allocations with command code 2902
2) Setting parameters for sending messages with 11-bit, or 29-bit identifier
3) Setting parameters for receiving messages with 11-bit, or 29-bit identifier
4) Enabling CAN communications, device variable *_*EnblCANComm*

4.3.1 Setting memory areas Command code 2902

With command code 2902 there is send buffer location, send trigger location, receive buffer location, receive flag location and amount of send and receive messages configurated.

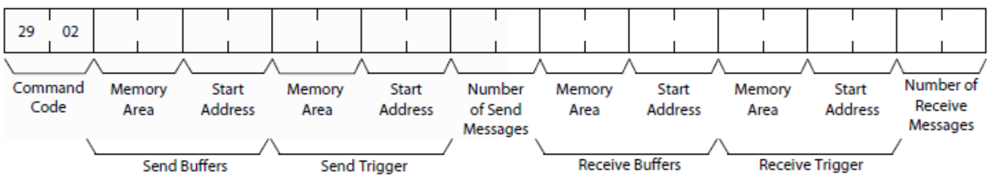

Figure 40. *CAN 2902 Command Block*

In test program the Send buffer area was programmed to start in 19200 area and Receive buffer are in 19700 area.

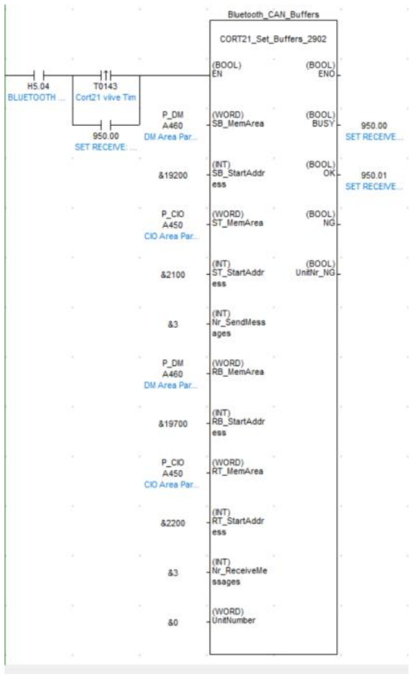

Figure 41. *Programmed Command Block*

4.3.2 Setting 11-bit or 29-bit Message Send Buffer (2903_4)

With command, 2903 there is possible to configured 11-bit send message buffer, and with command, 2904 there is possible to configured 29-bit send message buffer. In the used program, these commands are made in one block. Change of 11-bit and 29-bit receive message buffer is done by changing bool input in programmed function block with P_Off and P_On.

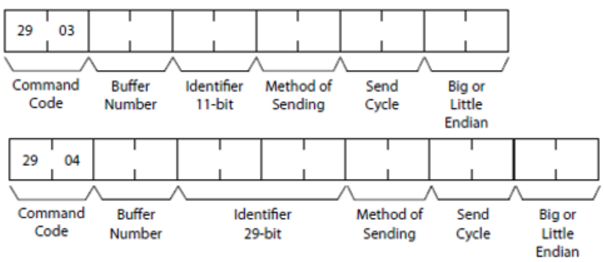

Figure 42. *CAN 2903 and 2904 Command Block*

In the test, there is 3 different CAN-Bluetooth communication bridge in use, so there is need to have 3 blocks for send buffer.

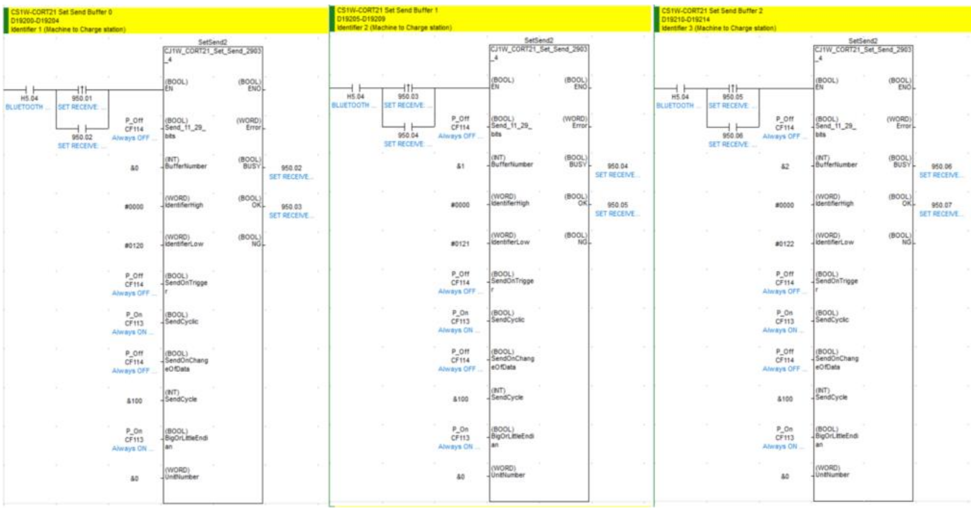

Figure 43. *Programmed send block*

4.3.3 Setting 11-bit of 29-bit Message Receive buffer (2905_6)

With command 2905 there is possible to configurate 11-bit receive message buffer, and with command 2906 there is possible to configurate 29-bit receive message buffer. In the used program these commands are made in one block. Change of 11-bit and 29-bit receive message buffer is done by changing bool input in programmed function block with P_Off and P_On.

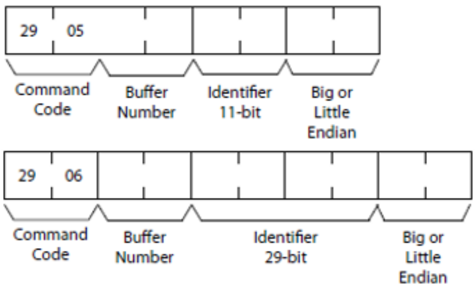

Figure 44. *CAN 2905 and 2906 Command Block*

Receive In the test, there is 3 different CAN-Bluetooth communication bridge in use, so there is need to have 3 blocks for receive buffer.

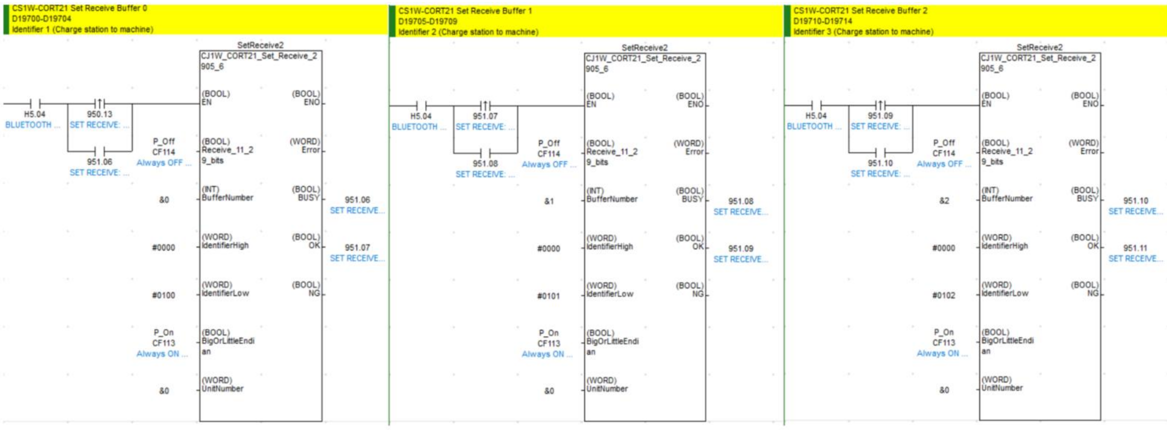

Figure 45. *Programmed receive block*

4.3.4 Setting 11-bit or 29-bit Direct Transmit message (2907_8)

With command 2907 there is possible to configurate 11-bit direct command that can be used to configuration of Proemion module throw CAN-bus, and with command 2908 there is possible to configurate 29-bit direct command. Change of 11-bit and 29-bit receive message buffer is done by changing bool input in programmed function block with P_Off and P_On.

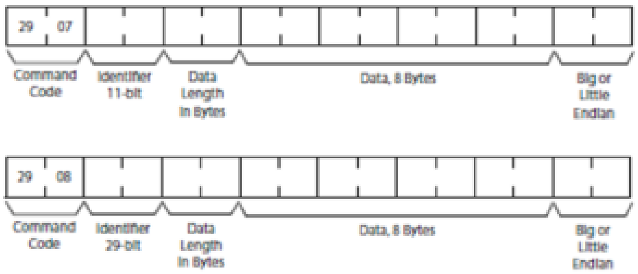

Figure 46. *CAN 2907 and 2908 Command Block*

For test cases Direct Transmit is used to configurate Proemion module. With block, in the data bytes there is parameters send in the module configuration.

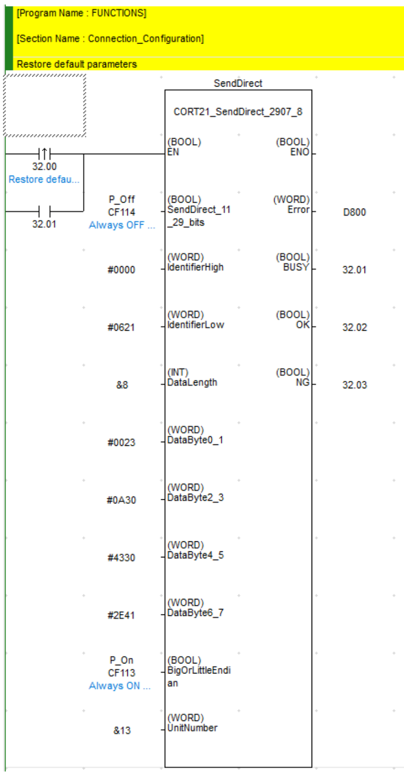

Figure 47. *Programmed Direct Command block*

4.3.5 Configuration with CANlink module configurator

At first CANlink wireless module is connected to computer via RS232-USB converter cable. At first, there is needed to establish connection with computer and CANlink wireless.

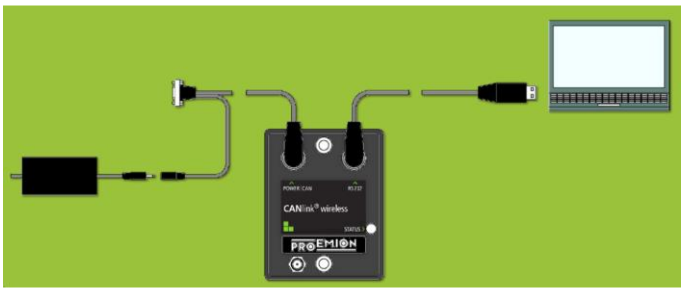

Figure 48. *CANlink module – PC cabel connection*

This starts with ensuring that correct COM port is selected for the USB-Serial adapter. Identification is managing from PC Device Manager under USB Serial port

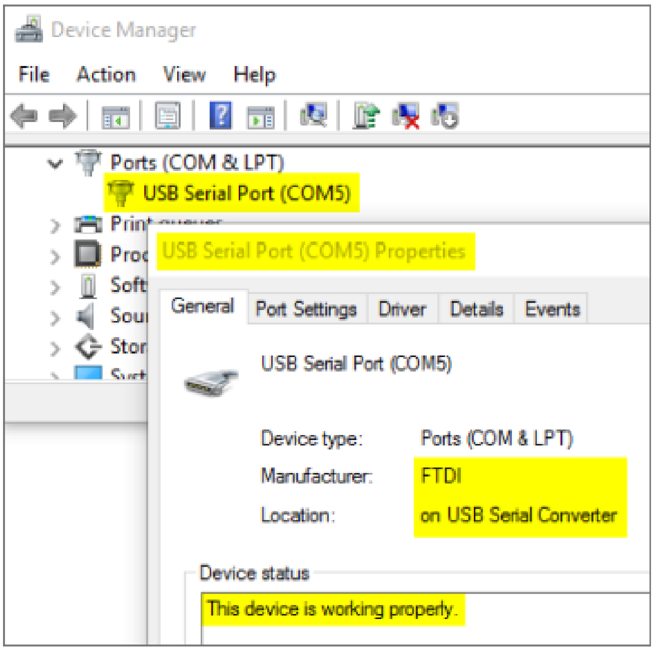

Figure 49. *USB serial port management*

4.3.6 Proemion module configuration

At CAN-Bluetooth communication build in CANlink module starts with module configuration. Each module is needed to configurate with CANlink wireless Configurator-software. Process of the unit configuration contains:

- Connecting the CANlink CAN-bus cable and configuration cable
- Defining Device parameters, CAN-bus baud rate, node id

With CANlink wireless Configuration-software, the configuration that is related to CAN-bus of the module is made, first basic configurations made to device includes CAN baud rate, CANopen node.

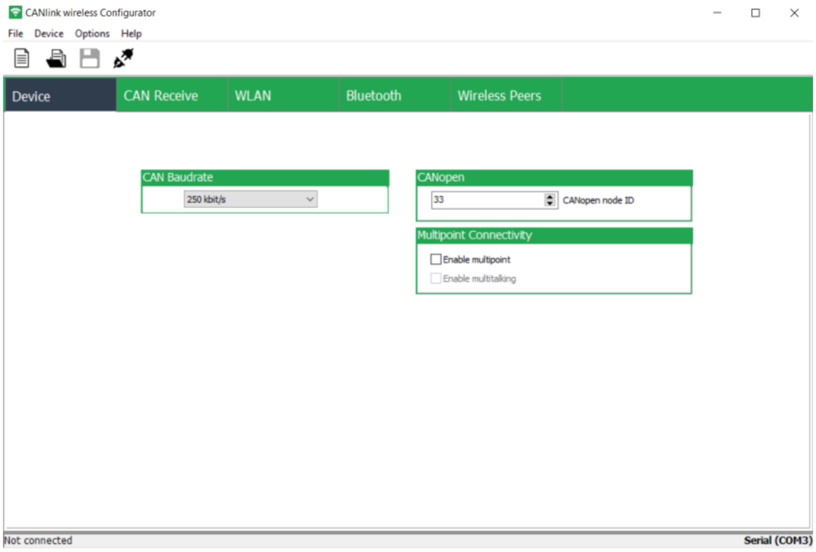

Figure 50. *CANlink wireless Configurator Device Screen*

For Bluetooth communication configuration includes enabling Bluetooth device configuration. With this it is needed to disable WLAN configuration. For Bluetooth communication it is needed to make possible for device to be discoverable and pairable.

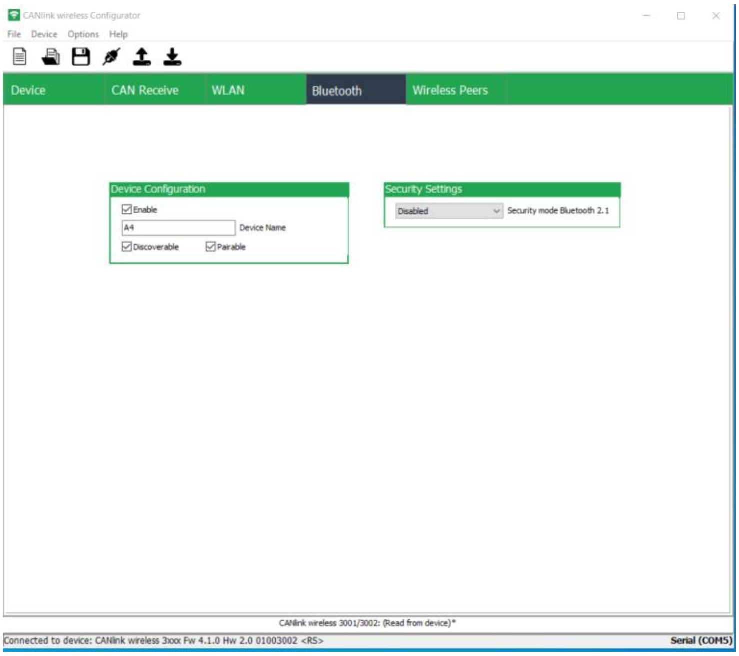

Figure 51. *CANlink wireless Configurator Bluetooth Screen*

When needed configurations are done, then configurations are written to device throw USB-Serial.

4.4 Communication test setup

Implemented system considers two Omron PLC and two CANlink Bluetooth bridge. This setup was used in testing, used as Master and Slave station. With PLC-to-PLC communication is compared in to Piconet communication between two Bluetooth devices where is one Master and one Slave. Master would be configurated in Stable Machine, and Slave could be configurated in Mobile Machine.

5. RESEARCH RESULTS

The objective of the test was to ensure undisturbed wireless communication between Mobile Machine and other machines. This chapter gives information about test cases results and how this used hardware is applicable with need for Kalmar products. Wireless communication technology has become more common in industry and mobile machinery. With the help of various wireless sensors and IoT solutions, the number of machine cables has been reduced, which has also reduced malfunctions.

All the tests were made in same environment. Controlling and monitoring system was done with laptops that had connection to PLC´s that controlled the communication and were used to following data transmission between Bluetooth modules.

5.1 Communication test

Test were made in same test setup and communication was monitored from Omron CX-Programmer Watch Sheet, so data that was changed were send and received correctly. The communication test was made in the office premises. Data exchange between PLC´s was done with Receive and Send buffer function blocks, where address of memory was created. Data what was wanted to send was defined in MOV(021) command where MOV functions source word was moved to specified word in buffer function. Data from Mobile Machine to other machine was send in 1s timing, so the visual noticing was able from Charger PLC Watch Sheet.

In the beginning, the communication between PLC-to-PLC with CANlink Bluetooth bridge, was tested and it worked correctly. Proemion CANlink 3000 Module´s configuration was made in with CANlink wireless Configurator software. Basic parameters were used and made with Proemion manual description.

PLC Name	Name	Address	Data Type / Format	FB Usage	Value	Value(...	Comment
ChargeStation_Machine	ReceiveDataFromChargeStationWord1	D19701	CHANNEL (Hex,Channel)				BLUETOOTH WORD 1 (RECEIVE)
ChargeStation_Machine	ReceiveDataFromChargeStationWord2	D19702	CHANNEL (Hex,Channel)				BLUETOOTH WORD 2 (RECEIVE)
ChargeStation_Machine	SendDataToChargeStationWord1	D19201	CHANNEL (Hex,Channel)				BLUETOOTH WORD 1 (SEND)
ChargeStation_Machine	SendDataToChargeStationWord2	D19202	CHANNEL (Hex,Channel)				BLUETOOTH WORD 2 (SEND)

Figure 52. *CX-Programmer Watch Sheet*

Communication was tested so that PLC program changed data between Mobile Machines PLC programs. End of the test, thirds module was added to network, so the effect of new module in network would be noticed.

In the second test, it was needed to make CANlink module configuration with Omron PLC. This configuration was made with SendDirect_2907_8 function block. Data that was sended was example the module name. Configuration Data was needed to be send in hex code if the index in module was in Uint mode and send in ascii mode if index was in string mode.

0x3002	0x04	Allow Pairing Bluetooth 2.0	UInt8	rw	1	0: Disabled 1: Enabled
0x3002	0x05	DeviceName	String	rw	0	Bluetooth Device Name

Figure 53. *CANlink wireless 3000 setup value examples*

After configuration that was decided to add, modules were restarted and checked functionally after that.

5.2 Discussion

This part of chapter gives summary about testing and possibility to use tested technologies for communication between Mobile Machine and other machines test systems.

5.2.1 Test results

Bluetooth communication at the first test worked correctly, when there were 2 devices communicating. Communication was disturbed if third device was started. These all modules were in factory settings, so stated module starts to make connection to modules that have settings discoverable and pairable options selected. When the third module was added to network it was found that communication between originally paired modules was disturbed.

Second test was focused to send configuration parameters to modules before starting to transfer data. Configuration, which was decided to make, was sent to modules, and after the PLC sent configuration, it was confirmed with Proemion CANlink Wireless Configurator software. After the confirmation the power was taken off from modules and restarted and checked the configuration after restart. Changed configuration was stayed in the module. There were found that all needed configurations for modules was able to send, so communication between modules was able start and stop from PLC program. Through this possibility the third module didn´t cause errors in communication between originally communicating modules.

5.2.2 Module configurations

One key research question was the possibility of using the chosen communication technology. Although Bluetooth technology is suitable as the chosen communication technology, due to the versatility of this use, programming of the selected products should be possible during each pairing of modules.

6. CONCLUSION AND FUTURE DECISIONS

In this thesis there was needed to gather information how wireless communication between two PLC´s would be able to add in CAN-bus would be able to transmit data from PLC to other PLC. The needed answers to gathered for the questions.

After theory research and researching the equipment manufacturers, the proposed technology and manufacturer was chosen. For wireless communication, the Bluetooth technology was chosen. Mobile Machines had Omron PLC with CAN-bus communication for internal functions. There were needed to have wireless communication between Mobile Machines and other machines, where could production process data exchange be possible. Implementation phase and testing indicates that chosen communication technology satisfy the expectations for communication exchange.

For future there is needed to have development to this process, so communication wouldn´t disturbed when other machines come near to paired Mobile Machine and paired other machine. There is needed to be identifier for Mobile Machines, which is slave, that communicate with Mobile Machine, which is master, and this identifier data is needed to send to master, so Stable Machine that is master knows which Mobile Machine it would need to pair. This identifier is possible to do with RFID reader in Stable Machine and tag that is installed in the Mobile Machine. With this solution the process will be surer.

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